PROCEEDINGS
THE INSTITUTION OF CIVIL ENGINEERS

PART I
JULY 1952

ORDINARY MEETING

19 February, 1952

HENRY FRANCIS CRONIN, C.B.E., M.C., B.Sc.(Eng.), Vice-President I.C.E., in the Chair.

The Chairman, having asked the members present to stand, said that :—

" After all that has been said, and said so eloquently, there is little which I can add by way of tribute to His late Majesty.

He was an Honorary Member of this Institution and on his accession to the Throne he became the Patron.

He was always greatly interested in all matters connected with Engineering and there are many in this room to-night who had the honour and the privilege of showing him some of the works they had either constructed or had to operate.

The keenness which he evinced on those occasions, the detailed questions which he asked, as well as the kindly understanding which he displayed, not only in the works themselves but in the staff of all grades connected with them, will always be a reminder of the considerate and thorough manner in which he fulfilled his public engagements.

His life was an example to us all, and well did he strive to fulfil Chaucer's advice to King Richard II :—

> ' Drede God, do law, love truth and worthinesse,
> And wed thy folk again to stedfastnesse' ".

The Council at their meeting that afternoon had approved Addresses of Condolence for submission to the present Meeting before they were presented to the Queen and Queen Mother.

The Chairman then read the two Addresses of Condolence, in which the Meeting concurred.

The Chairman, the members still standing, said that the Council had passed the following Resolution on the death of Sir Reginald Stradling, a former Vice-President of the Institution :

> " That the Council record the deep regret with which they have learned of the death of Sir Reginald Edward Stradling, C.B., M.C., D.Sc., Ph.D., F.R.S., whose service on the Council for ten years was recognized by his election as Vice-President in November 1945. He was obliged to decline nomination to the Presidency in 1947, and again in 1948, owing to ill-health. The Council desire to place on record their appreciation of the services rendered by him to the Institution, and to express to Lady Stradling and the members of his family sincere sympathy in their bereavement."

The Meeting concurred in the Resolution.

The Council reported that they had recently transferred to the class of

Members

Leslie William Harold Hall, B.Sc. (Eng.) (*Lond.*).
Ronald Chalmers Kelt, M.B.E., B.Sc. (*St. Andrews*).
Henry Leslie Hugh Kerley, B.Sc. (Eng.) (*Lond.*).
Frederick Charles Martin.
Edmund Norman Underwood, B.Sc. (Eng.) (*Lond.*).
Ernest Victor Walshe, M.Sc. (*Belfast*).
Arthur Leonard Wheeler, B.Sc. (Eng.) (*Lond.*).

and had admitted as

Students

David Allen.
Ralph Anderson.
David Balfour.
Clifford Raymond Barnett.
Desmond Beall.
Norman Francis Bickley.
Graham Ure Biggart.
Eric Dunstan Bill.
Cedric Charles Blagg.
Alexander Eveleigh Blair.
Antony Richard Booth.
Reginald Frank Bowman.
Reginald George Hector Boyes.
Robert Bradley.
Robert Ernest Burton.
Christopher David Burtt.
John Macfarlane Cairncross, B.Sc. (*St Andrews*).
Alan Caunce.
Edward James Clague.
Brian Thomas Clark.
Roy Victor Clayton.
Ronald Cliffe.
Lawrence Allan Colbert, B.Sc. (Eng.) (*Lond.*).
Derek Henry Corlett.
Brian Victor Daniels.
Brian Leslie Dobbs.
Malcolm Carl Donnelly.
David Mellor Evans.
James David Fielding.
Peter Kingsley Filshie.
William Michael Flanagan.
Tom Walter Fletcher, B.Sc. (*Nottingham*).
Geoffrey Foster.
Noel Howard Fox.
John Peter Froehlich.
David Leonard Gell.
David Hall Gibson.

JOHN CAMPBELL GOODRIDGE.
EDWARD WALTER GREAVES.
MICHAEL GEORGE HANDCOCK.
CHRISTIAN HANSSON.
VICTOR DENNIS HARE.
FRANK HENRY HART.
ALEXANDER THOMAS HAWKINS.
ERIC JAMES EDWARD HEATON.
RODNEY MICHAEL HIGGINS.
THOMAS WILLIAM HILL.
JACK HOLLAND.
HUGH WADDELL HOOD, B.Sc. (*Glas.*).
JOHN ROBERT HORROCKS.
ROSS KENRICK HOWARD.
JOHN ERYL HUGHES.
KENNETH HUTTON.
BRIAN JAMES JACKSON.
PAUL JOHN KERKHOFF.
MAURICE PETER KNELL, B.Sc. (Eng.) (*Lond.*).
JOHN FRANCIS LEJEUNE.
JOHN MICHAEL LOMAX.
PATRICK JOSEPH MCCARTER.
RONALD JAMES HUGO MCGRATH.
STUART MANSER.
DENIS FRANCIS MENDES, B.Sc. (*Glas.*).
JOHN NELSEY MIDDLE.
JAMES EDWARD MOORE.
DAVID CHARLES NEALE.
GEORGE KEITH NEWSOME.
MURRAY NICOLL.
DAVID IRVINE PATERSON.
ROY ALBERT PEEL.
JOHN MILNE PETRIE.
STEVEN PONT.
KEITH PONTIN.
ROGER MELVILLE TAUNTON RAIKES, B.A. (*Oxon.*).
JOHN REGINALD RAWSTHORNE.
ARCHIBALD REITH.
JOHN ARTHUR RHODES.
ALAN RIDLEY.
JOHN RICHARD ROSEWARNE.
PETER ARTHUR RUTTER.
ROBERT FRANK SCAIFE.
BRIAN SEVERN, B.A. (*Oxon.*).
BRYAN SHEPHERD.
ALAN SHEWARD.
DONALD EDWARD SHUKER.
MICHAEL JEREMY CHARLES SIMMONDS.
KENNETH FRANCIS SPARKES.
DAVID BRIAN STONE.
ARTHUR TOWNSON.
DAVID EDWARD THOMAS TRY.
JAMES LESLIE TUNNICLIFFE.
ARTHUR TYLDESLEY.
PETER BOYD WADDICAR.
DONALD ANCRUM WALKER, B.Sc. (*Witwatersrand*).
DAVID WATKINSON.
DEREK JOHN BRYANT WATTS.
ROY ALAN WEBB.
ALAN KEITH WETTON.
ALAN WHETTON.
JOHN CHARLES LEE WHITE.
STANLEY OWEN WHITEHOUSE, B.Sc. (Eng.) *Lond.*).
GEOFFREY THEO WILLIAMS.
MICHAEL KINGSLEY WILLIAMS.
DAVID HENRY WITHERS.
PETER LYALL WRIGHT.

The Scrutineers reported that the following had been duly elected as

Associate Members

WILLIAM BRODIE ACHESON.
PETER ACKERS, B.Sc. (Eng.) (*Lond.*).
ROBERT MCGREGOR AIRLIE.
JOHN ALLEN, M.Sc. (*Manchester*), Ph.D.
KENNETH JOHN AVENT.
STANISLAW ADAM BARDECKI.
GEORGE PATRICK BARNET, B.Sc. (*Edin.*).
LESLIE CLAUDE ARTHUR BIRD.
NELSON CHARLES BOWMAN, Stud. I.C.E.
EDWARD GRAHAM WHITTINGTON BUSH.
JAMES SINCLAIR CAMLIN, B.Sc. (*Belfast*).
HUGH CECIL GODFREY CARTWRIGHT-TAYLOR, B.A. (*Cantab.*).
RONALD WILLIAM CAWTE, B.Sc. (Eng.) (*Lond.*).
JOHN ROBERT WILLIAM CLARK, M.Eng. (*Sheffield*).
HENRY JOHN COLTER.
CYRIL DERRICK DAVIES, Stud. I.C.E.
LESLIE DAVIES, B.Sc. (Eng.) (*Lond.*).
FRANK ROBERT DAVIS, B.Sc. (*Birmingham*).
RICHARD FARRINGTON EVANS, B.A. (*Cantab.*).
GEOFFREY LAWRENCE FAULKNER, B.Eng. (*Sheffield*).
EAMON PETER FITZGERALD, B.E. (*National*).
WILLIAM JAMES FOUBISTER, B.Sc. (*Aberdeen*).
JOHN LESTER HAROLD FOX.
SAMUEL JAMES GARTON, B.Sc. (*Leeds*).
DENNIS STANLEY GEBHARDT, B.Sc. (*Witwatersrand*).
JOHN EDWARD GIBSON, M.Sc. (*Durham*), Ph.D.
JOHN GEORGE GIE, B.Sc. (*Cape Town*).
JOHN CLEMENT GILLBEE.

Thomas Gilmour, B.Sc. (*Glas.*).
Theodore Abner Goddard, B.Sc. (Eng.) (*Lond.*).
Arthur Richard Goode, B.Sc. (*Birmingham*).
Lionel James Govett, B.Sc. (Eng.) (*Lond.*).
Geoffrey Herbert Grundy, B.Sc. (*Manchester*).
Charles Edgar Hallett, B.Sc. (Eng.) (*Lond.*).
Douglas Ian Halstead, B.Sc. (Eng.) (*Lond.*).
Ian Lamb Hamilton, B.Sc. (*Glas.*), Stud. I.C.E.
Kenneth Latimer Hardaker, M.A. (*Cantab.*).
James Heard.
Gordon Nicol Henderson, B.Sc. (*Aberdeen*).
James William Heslam.
John Andrew Hilton.
Neil Holland Hopley, B.Eng. (*Liverpool*).
George Horne.
William Howie, B.Sc. (*Glas.*).
Lewis Owen Hurd.
Peter Hastings Hyslop, D.S.C., B.Sc. (*Edin.*).
William Gareth James, B.Sc. (Eng.) (*Lond.*).
Fred Robert Jarvis.
William Howard Jones.
Edward Allan Leonard Keith, B.Sc. (Eng.) (*Lond.*).
George Stephen Kirkbride, B.Sc. (*Belfast*).
Reginald William Kirwan, M.A., M.A.I. (*Dublin*).
Johnston Stewart Lamb, B.Sc. (*Edin.*).
Roland Davey Law, B.Sc. (Eng.) (*Lond.*).
Robert Conway Leese.
James Lambridge Le Page, B.C.E. (*Melbourne*).
Douglas Clement Arthur List.
Henry Charles Lock.
Jack Alexander Burfitt Lovell, B.Sc. (Eng.) (*Lond.*).
Thomas Mathew McCann.
John McClure, B.Sc. (*Belfast*).
John Douglas McIntosh, M.Sc. (*Durham*).
Donald McKay, B.Sc. (*Leeds*).
Brendan Gerard McKeown, B.Sc. (*Belfast*), Stud. I.C.E.
George Edwin McLean, B.Sc. (Eng.) (*Lond.*).
Edward Almevic Leonard Maguire, M.A. (*Cantab.*).
Frank Manning, B.E. (*National*).
Ian Tweedie Millar, B.Sc. (*Glas.*), Stud. I.C.E.
Reggie Millburn.
Nevil William Morley.
Charles Henry Moslin.
Thomas Albert Murdock.
David Edward Pepler Norton, B.A. (*Cantab.*).
Caesar Edward Otway, M.C., B.A. (*Cantab.*).
Kenneth Francis Paddock.
Thomas Graham Peirson, B.A. (*Cantab.*).
Alfred Edward John Pepper, M.C., B.Sc. (*Durham*).
Peter Donald Teasdale Pescod, B.Sc. (Eng.) (*Lond.*).
Herbert William Pethick, B.Sc. (Eng.) (*Lond.*).
Edmund Argent Phillips.
Ian Robert Thomas Pollock.
John Powlesland, B.A. (*Cantab.*) Stud. I.C.E.
John Price, B.Sc. (*Wales*).
David William Quinon, B.Sc. (Eng.) (*Lond.*), Stud. I.C.E.
Michael Philip Rathbone, M.Eng. (*Liverpool*).
Norman Horace Rivett, B.Sc. (Eng.) (*Lond.*).
Joseph Lister Rodger, B.Sc. (Eng.) (*Lond.*).
Charles George Sang, B.Sc. (*Aberdeen*).
Leslie Eric Schraer, B.Sc. (Eng.) (*Lond.*).
John Harold Simpson, B.Sc. (*Belfast*).
Robert Gordon Sloss, M.Eng. (*Liverpool*), Stud. I.C.E.
Martyn Grenfell Spencer.
Donald Tate, B.Sc. (Eng.) (*Lond.*).
Donald Kenney Taylor.
Richard Dudley Taylor, M.C., B.Sc. (*Birmingham*).
Dudley George Henry Trembath, M.A. (*Cantab.*).
Cyril Francis Trigg, M.Sc. (*Wales*).
Ian Mansergh Varley, B.Sc. (Eng.) (*Lond.*), Stud. I.C.E.
Salagame Venkatramaiah, M.Sc. (Eng.) (*Lond.*), B.Sc., B.E. (*Mysore*).
Charles Geoffrey Walker, B.Eng. (*Sheffield*).
Bernard Leslie Watkins, M.A. (*Cantab.*).
Thomas Whipp, B.Eng. (*Liverpool*).
John Walter White.
Arthur Geoffrey Whiteside, M.A. (*Cantab.*).
Henry Styring Whittaker, M.Eng. (*Sheffield*).

JOHN MORLEY WOOD WHITTLE, B.Sc. (*Durham*).
JAMES KEITH BROOKE WILLIAMS, B.Eng. (*Liverpool*).
ALAN GEORGE WILLIAMSON, B.A. (*Cantab.*).
JOHN WILSON.
PETER WOLF, B.Sc. (*Durham*).
ROBERT WOODS, Stud. I.C.E.
GEOFFREY ALEXANDER WOODWARD, B.A. (*Oxon.*), Stud. I.C.E.
GEORGE ZERONIAN, B.Sc.Tech. (*Manchester*).

The following Paper was presented for discussion and, on the motion of the Chairman, the thanks of the Institution were accorded to the Author.

Paper No. 5856

"Festival of Britain, 1951 : The South Bank Exhibition Buildings"

by

Sir Hugh Casson, M.A., F.R.I.B.A., Ralph Freeman, C.B.E., M.A., M.I.C.E., and Robert Trafford James, O.B.E., M.I.C.E.

SYNOPSIS

The construction work on the South Bank comprised four principal items, namely the new River Wall, the Royal Festival Hall, site works (general levelling, main services and paving), and the twenty-nine Exhibition Buildings. The structural design and erection of the Exhibition Buildings and the inter-relation of their construction with the other works on the site forms the subject of the Paper.

An account is given of the early development of the Exhibition plan and the considerations governing the lay-out of the site. The architectural designs produced striking and original effects.

The Paper describes the measures adopted to achieve completion of the buildings within the very short period available for their construction ; and to co-ordinate the building programme with all the other works to ensure that none were impeded.

The most serious of all the problems encountered were those arising from the limited time and the congestion of the site. The architects for the buildings were not commissioned until March 1949. The first outline sketch designs were available in May. Production of working detail drawings was not in full swing until towards the end of 1949. From then on until the opening day followed a race between the making of working drawings and the needs of construction on the site.

The general basis adopted for foundation and structural design is outlined, together with the salient structural features of some of the buildings.

Introduction

The South Bank Exhibition was only one, if perhaps the most important, of the official features of the Festival of Britain. Before discussing its technical organization and its structures, it is therefore necessary to sketch very briefly the general background against which it was planned. The idea of the Festival was first suggested by Mr (now Sir) Gerald Barry, at that time editor of the *News Chronicle*, in an open letter to the Government dated the 14th September, 1945. A Government committee reported favourably on the proposal and in December 1947 it was announced that there would be held, in 1951, a Festival designed to mark the centenary of the Great Exhibition of 1851 and to demonstrate, on a national scale,

British achievements in the arts, architecture, science, technology, and industrial design.

To consider how the Festival should be carried out, the Government set up a General Advisory Council of voluntarily serving men and women, all of them distinguished in some field of national life, under the chairmanship of Lord Ismay. At the same time a new Government Department, known as the Festival of Britain Office, was formed and Mr Barry was appointed its Director General.

Early Planning

During the first months of 1948 the Executive Committee and Staff of the Department were gradually built up and additional advisory councils appointed ; among these was the Council for Architecture, Town Planning, and Building Research under the chairmanship of Mr Howard V. Lobb, C.B.E. By mid-summer there was prepared a draft programme which incorporated as its centre piece what was eventually to become the South Bank Exhibition, but known at the time as the Combined Exhibition. The responsibility for devising the theme of this exhibition, and indeed of all others in the Festival programme, was placed in the hands of the Festival Presentation Panel under the chairmanship of Gerald Barry. A sub-committee of the panel, known as the Design Group, was appointed to make the recommendations for the carrying of this theme into visual effect as soon as the story and the site were confirmed.

In August 1948 the prospects of the Combined Exhibition were not rosy. Several sites had been suggested and examined, only to be rejected for one reason or another. The economic background of Great Britain, even in those days, seemed precarious and requests to Ministers for labour and materials did not seem to be favourably received.

These early months of uncertainty were nevertheless usefully spent in working on the Exhibition theme and trying to put it into the form of an architectural programme. In brief, it was eventually decided that the British contribution to civilization could be portrayed as springing from the combination of two forces, the initiative of the people and the resources of their native land. The background of this picture was to be the working world of today, a particular aspect of which was to give the title to each Pavilion. It was also agreed that the Exhibition should tell a continuous story, and that a total area of 400,000 square feet of covered space was to be aimed at. One of the first and hardest tasks of the Presentation Panel was to break this total figure down into reasonable allotments for each chapter of the story, bearing in mind not only the relative importance of each subject but the scale and character of the exhibits, be they microscopes or railway engines, which were to be the illustrations. By the end of August this problem had been solved in broad outline. By this time also the South Bank site seemed to be an almost certain choice.

The Design Group's first tasks were to arrange for an accurate survey to be made of the site, since no reliable plan existed ; and to investigate and weigh up the physical difficulties with which they were faced.

The site (*Fig. 7* *) had, of course, splendid advantages—principally its magnificent central position in the very heart of London and its river frontage which, to the eye at least, almost doubled its area. It had its disadvantages too. It was small, only 27 acres in extent ; it had only one tree ; and Charing Cross Railway Bridge severed it in two. And there were other difficulties. Half the site, it seemed, was on lease to the Ministry of Works, who were about to start on an office block. Downstream of the railway bridge, the London County Council was already engaged on preliminaries for the Royal Festival Hall.[1] Along the full river frontage, work was shortly to begin on a new retaining wall (*Fig. 8*). (This, of course was also an advantage, for the land to be reclaimed would increase the area of the site by about one-seventh). Beneath the railway arches were a number of snugly-housed tenants whose leases and rights of access did not expire in some cases until 1951 ; and through the heart of the site ran a public right of way in the shape of the approach path to Hungerford Footbridge.

The Master Plan

Before much drawing-board work could be done, therefore, it was obviously necessary to sort out these complications. Constant, almost daily, meetings took place with the many interested authorities concerned, in particular with the London County Council (the Festival's landlords), the Railway Executive, London Transport, the Police, and the Port of London Authority. The situation soon improved. The Ministry of Works agreed to postpone work on their office block. Hungerford Footbridge could and would be extended back to York Road over the site. Positions for the river landing stages were agreed with the Ministry of Transport and the Port of London Authority. Consultations with London Transport and the Railway Executive settled the proposed underground and overhead links with Waterloo Station. Main entrances and exits were agreed with the Police.

While these negotiations were in hand the Design Group continued to work upon the master plan. The main task was to devise a lay-out which would ensure well-arranged circulation and points of access, ample and well distributed restaurant, lavatory, and exhibition services and, most important of all, an arrangement of Pavilions which would be thematically workable and visually exciting. This was not so easy as it sounds, partly because of inherent restrictions of the site and partly because so few statistics of previous exhibitions seemed to be relevant to this particular one.

* *Figs 6* to *16* inclusive are all photographs and appear between pp. 364 and 365.

[1] The references are given on p. 370.

At the outset, four basic if rather arbitrary decisions were taken :—

(1) That the site should be linked, visually and physically, with Trafalgar Square and thus with the very heart of London. (This was to be achieved later by the Bailey Bridge.) (*Fig. 10.*)

(2) That the central and dominating structure should be a saucer dome which, so far as could be seen, had never previously been used in other exhibitions and was in itself a visually exciting shape. (This of course eventually became the Dome of Discovery.[2])

(3) That since the theme was divided into two main chapters—the land and the people—the railway bridge should act as dividing agent.

(4) That since the site was so small any grand-manner lay-out was out of the question. Impressive vistas and monumental compositions clearly could not be attained in an area whose extent could be wholly comprehended in a single glance.

In implementing these decisions upon paper, the Design Group took into account the view across the Thames and determined which views of the north bank should be given prominence (for example, the view of St Paul's from the Thameside Restaurant under Waterloo Bridge).

By November, the first lay-out plan was ready for discussion. At this stage thought was being given to the methods to be employed for translating design into construction. The Festival Office decided, after consultation with other Government departments, to enlist the aid of a firm of consulting engineers to carry into effect the scheme envisaged by the Festival Office, the intention being that the firm should supervise the whole of the building work.

The Design Group and individual architects would thus be left free to work on their lay-out plans, building designs, management and display requirements and so forth, without simultaneously having to concern themselves with problems of construction.

Figs 1 and 2, Plate 1, and Fig. 3, Plate 2, show the three main stages in the development of the master plan.

Architectural Design Policy

The master plan was presented for final approval within the Festival Office in December 1948. January 1949 was spent in consulting and seeking the comments of the many interested authorities and obtaining their approvals. It was not until February that the Festival Office could

settle the next and vital stage, the design policy for the buildings. The alternative courses open were :—

(1) To make use of standardized types of buildings and adapt them where possible. This was rejected as being inflexible and because of Government advice that not sufficient variety of such buildings would be readily available.

(2) To settle one or more modular systems of construction which all designers would be instructed to follow. This was rejected because at that time it was felt that such a system would fail to ensure the broadest possible spread of load upon the building materials industry.

(3) To brief the architects as carefully as possible and to leave them alone to develop their designs.

This last was the course adopted, with full realization that coherence might be the more difficult to achieve, but on the other hand that it offered better chances of visual excitement and lively demonstration of structural techniques in the widest range of building materials. A separate architect was commissioned for each Pavilion or Zone, except that two of these commissions were made subjects of competitions, one for a restaurant (later abandoned as an economy measure) and the other for what was known at the time as the Vertical Feature. By the 1st February, the list of architects had been submitted for approval by the Architecture Council and others concerned ; and by the 1st March each architect had been given his outline brief and his building line.

Engineering Design and Administration

The consulting engineers were first approached by the Festival Office in February 1949 for advice on the structural design and construction of the Dome of Discovery. Several firms of consultants were considered for the wider task of supervision of construction of all the Exhibition buildings. Eventually in April this commission was offered to and accepted by the firm who had been approached for advice on the Dome. The duties assigned to the consultants were substantially as stated in the letter of appointment, relevant extracts of which are reprinted in Appendix I. Thus, whereas each architect was responsible to the Festival Office for the lay-out and details of his building, responsibility for the direction of all construction, not only foundations and structural framework, was to be solely in the hands of the engineers.

This task was entrusted to the engineers because :—

(a) Time was too short to permit the evolution of an administrative system whereby a number of independent architects could issue their own instructions and drawings to a contractor.

Centralized direction of construction and administration of building contracts was essential for speed.

(b) The first step in any case was to get structural designs under way, construction of foundations started, and steelwork and other principal fabricated items ordered, concurrently with the development of the architects' plans.

It will be observed from Appendix I that a distinction was drawn between building construction and " display " work. The latter was to comprise all interior fittings, furnishings, stands, small structures incidental to exhibits, display lighting, etc., in Exhibition Pavilions, restaurants, and other places open to the public. These interior works were to be supervised by the Display Construction branch of the Festival Office itself.

As plans developed, however, it became expedient to transfer into the orbit of building construction a number of items which strictly belonged to the " display " category. Whenever it appeared that over-all progress would be aided this was done. Typical instances were : the display work in the Transport Pavilion, interior decoration and fitting of restaurants, and display electric wiring.

It was not easy to allot priorities for tackling the seemingly extensive vista of separate problems requiring urgent attention. Four matters received immediate consideration. First, the Dome : the design and construction of this building has been described fully in another Paper [2] ; it is enough to say here that the whole of the structural design was completed, wind tunnel experiments conducted, competitive tenders invited for fabrication and erection of the roof of this building, between May and August 1949. Second : decisions on the system of foundations to be employed generally, together with basic guiding directives on structural materials and design. Third : consultation with all the other architects upon the design of their building structures. And fourth : consideration of the number and form of the main building contracts.

As has been seen, the architects had been commissioned more than a month before the consulting engineers were appointed. Some of the architects had to design buildings of considerable size and with several suspended floors ; or wished to feature, in their designs, novel structural techniques evolved by engineers with whom they customarily collaborated. They needed engineers from the very outset of their work. Thus by the time the main consultants came on the scene, some architects were already working with privately-appointed engineers of their own choice. Any potential difficulty was overcome by a compromise whereby these engineers continued to work jointly with their architects, responsibility to the Festival Office for structural safety and stability and for construction and contractual matters being retained by the main consultants.

A complete list of the Exhibition buildings, together with the names of the architects (including " private " engineers, where appointed), general contractors and structural sub-contractors, is given in Table 1.

TABLE 1.—LIST OF EXHIBITION BUILDINGS, ARCHITECTS, AND CONTRACTORS

Building	Architect (and "private" engineer where applicable)	General contractor	Structural subcontractor	Remarks
Station Gate, Rocket Cafeteria and Police Block	Sir John Burnet, Tait and Partners	Richard Costain Ltd	Aston Construction Co. Ltd	Laminated arches, designed by Timber Development Assocn.
Information Offices and Screen	Architects' Co-operative Partnership (Ove Arup & Partners—design of foundations and structure)	do.	Scaffolding (Great Britain) Ltd	
Post Office	do.	do.	Dawnays Ltd	
Fairway Café	do.	do.		
Turnstile Canopy	do.	do.		
Minerals of the Island	do.	do.		
Management Offices and Royal Pavilion	do.	do.	Scaffolding (Great Britain) Ltd and English Bridge & Structural Engineering Co. Ltd	Royal Pavilion Roof designed by Timber Development Assocn.
Natural Scene and Country	Brian O'Rorke	do.	S. & C. Walmsley Ltd	
Power and Production	G. Grenfell Baines and H. J. Reifenberg (F. J. Samuely—design of structure)	do.	Scaffolding (Great Britain) Ltd	
'51 Bar	Leonard Manasseh	do.	Wm. Bain & Co. Ltd	
Water Tower	Leonard Manasseh (F. J. Samuely—design of structure)	do.	Commercial Welders Ltd	
Sea and Ships	Basil Spence & Partners	do.	Fleming Bros, Ltd	Cascade Fountain designed by Richard Huws.

TABLE 1—(*continued*)

Building	Architect (and "private" engineer where applicable)	General contractor	Structural subcontractor	Remarks
Skylon	Powell & Moya (F. J. Samuely—design of structure)	Richard Costain Ltd	British Insulated Callenders Construction Co. Ltd	Wind-tunnel experiments and investigations by Dr N. A. V. Piercy.
Regatta Restaurant and Press Centre	Design Research Unit	do.	Matthew T. Shaw & Co. Ltd	
Masts on Bailey Bridge. .	do.	do.	Stewarts & Lloyds Ltd, Saunders-Roe (Anglesey) Ltd, Carter Horseley Ltd	Wind-driven spinners designed by Richard Huws. Wind-tunnel experiments and investigations by Dr N. A. V. Piercy.
Victoria Embankment Entrance Canopy, etc.	do.	do.	Samuel Elliott & Sons Ltd	
Transport	Arcon (F. J. Samuely and Dr H. Gottfeldt — design of structure)	do.	United Steel Structural Co. Ltd	
Main Fairway, Fountain Lake, and Conical Entrance features	H. T. Cadbury-Brown	do.	Horseley Bridge and Thomas Piggott Ltd (Conical Entrance features)	Design of hydraulics and under-water lighting and supervision of pumping installations for this and all other fountains by Ministry of Works, Engineering Division.
Land of Britain	do.	do.	S. & C. Walmsley Ltd	
People of Britain . . .	do.	do.	do.	
Turntable Café	do.	do.	Laidlaw Smith & Co.	
Dome of Discovery . . .	Ralph Tubbs	do.	Horseley Bridge & Thomas Piggott Ltd (main roof structure) S. & C. Walmsley Ltd (gallery steelwork)	Wind-tunnel experiments and investigations by Dr N. A. V. Piercy.

TABLE 1—(*continued*)

Building	Architect (and "private" engineer where applicable)	General contractor	Structural subcontractor	Remarks
The Lion and the Unicorn .	Goodden and Russell	Holland & Hannen and Cubitts Ltd	S. & C. Walmsley Ltd	Timber lamella structure design by E. Lewis.
Television and Telecinema .	Wells Coates	do.	Steel Ceilings Ltd	
Introduction to Homes and Gardens	Denis Clarke-Hall (L. W. Elliott—design of structure)	do.	Sheratt & Smith Ltd	
Homes and Gardens. . .	Katz & Vaughan	do.	Steel Scaffolding Co. Ltd Boulton & Paul Ltd	Architect for Bandstand—G. Epstein.
Waterloo Bridge Gate and Harbour Bar	Fry, Drew & Partners (Ove Arup & Partners—design of foundations and structure)	Kirk and Kirk Ltd	Scaffolding (Great Britain) Ltd (Canopies, etc.)	
Viewing Tower	do.	do.	English Bridge & Structural Engineering Co. Ltd	
Schools and Health . . .	do.	do.		
Thameside Restaurant . .	do.	do.	Alphamin Ltd	
Sport	Gordon Bowyer (L. L. Kenchington—design of structure)	do.	Johnson Bros. (Steel Erectors) Ltd	
Shot Tower	Hugh Casson	Holland & Hannen and Cubitts Ltd	Horseley Bridge & Thomas Piggott Ltd	
Centenary Pavilion . . .	do.	do.	Walter MacFarlane & Co. Ltd	
Boathouse, Pools and Sports arena	do.	do.		

TABLE 1—(*continued*)

Building	Architect (and "private" engineer where applicable)	General contractor	Structural subcontractor	Remarks
Seaside Velarium and Viewing Platforms	Brown & Chamberlin	Holland & Hannen and Cubitts Ltd	Stewarts & Lloyds Ltd, British Ropes Ltd, London Welding Co. Ltd	
Staff Quarters, Administration, and Canteen	Edward D. Mills	do.	S. & C. Walmsley Ltd	
B.B.C. Central Control and G.P.O. Telephone Exchange	Drake, Lasdun and Goodesmith	do.	Smith Walker Ltd	
Pavings, Gardens, Flower Boxes, Trees and Landscape treatment generally	H. F. Clark Marie Shephard Peter Shepeard G. P. Youngman	*Trees*—Annis & Co. Ltd *Civil Engineering Works*— Richard Costain Ltd Holland & Hannen and Cubitts Ltd, Kirk & Kirk Ltd		Landscape Subcontractors—Marcel de Smet Ltd, Gavin Jones Ltd, Winkfield Manor Nurseries Ltd.
Decoration of Hungerford Footbridge and Sutton Walk Entrance to Royal Festival Hall	Unit 6	Holland & Hannen and Cubitts Ltd		

Foundations

It was apparent from the first sketch designs that in many of the buildings the column loads would not be small. Records of several borings made by the London County Council and London Transport were available. Excavation for the Royal Festival Hall had exposed the subsoil strata very clearly. There was a variable surface layer of about 4 or 5 feet of made-up ground, rubble, etc.; underneath that was about 8 to 10 feet of "bungum" or very soft clay; and beneath that was the gravel. The groundwater fluctuated at an average level of about + 7 O.D.* relative to finished surface levels planned to be between + 11 and + 18. The area reclaimed behind the new river wall was of filled rubble.

On and in the surface layers over the rest of the site was a jumbled and uncharted mass of old foundations, basements, and buried remains of still older buildings. There was no information about the extent, depth, or character of this hidden masonry.

Bearing in mind the limited life the buildings were to have, some risk of settlement could be accepted. The decision was therefore made to place the footings on the rubble crust, keeping them as shallow as possible, with the object of not breaking through the crust but making the utmost use of it. Before the foundations were laid the excavated areas under them were to be consolidated as well as possible by heavy rolling or mechanical punning. A very careful watch was kept for old basements, manholes, and similar cavities.

Where possible, strip footings were employed to facilitate consolidation by rolling. In general, design foundation pressures were of the order of $\frac{1}{2}$ ton per square foot but some discretion was used, according to the building and the degree of resistance to differential settlement desirable.

Adoption of this type of foundation brought consequential problems, not the least of which arose from the spread required for heavy stanchion loads in combination with the need for underground ducts and routes for the very numerous services. Arbitrary decisions often had to be taken on the space and depth required for sections of these routes before other sections of the routes had been approved, in order to get foundation work under way.

Superstructure

In 1949, structural steel, although still controlled, was relatively plentiful. Aluminium alloy was also readily obtainable, but for all ordinary purposes prohibitive in cost. It was decided in general to use steel frameworks, with bolted joints for speed of erection and ease of dismantling; pre-cast concrete units, again for speed and simplicity in construction and demolition and to save shuttering; asbestos cement in

* See Mr Fuller's contribution to the discussion, p. 374, and Author's reply, p. 387.

all its range of products; and various proprietary types of pressed sheet-metal roofing were also to be given a chance. Cement-impregnated wood-wool slabbing seemed an attractively cheap medium for roofs. Imported softwood, that most valuable and versatile of building materials, was to be avoided by every possible artifice; this was to be the cause of many headaches later on. Much thought and ingenuity was lavished to avoid its use; but in spite of all efforts mistakes sometimes occurred which could so cheaply and easily have been put right by the carpenters and joiners had they been free to ply their trade in the traditional manner.

Building Contracts

Mention has already been made of the River Wall, Concert Hall, and other works of magnitude to be carried out on the site, all of which were integrated with the Exhibition project as a whole.

In May 1949, the Festival Office prepared an exhibition of the architects' sketch designs and models of the buildings proposed. Examination of these revealed that many of the structures were far from orthodox; materials were to be used in various strange ways; and an immense amount of work would be required to transform what were little more than visual impressions of buildings into the reality of working drawings and specifications for construction. Moreover, before any precise designing could be started, the sketch plans would have to be correlated to the master plan and outline estimates of cost prepared. The estimates would have to be compared with the Festival Office budgets and, where necessary, cuts made or compromises reached.

It followed that if the buildings were to be substantially finished by the end of 1950 any idea of proceeding on normal lines—completing the designs, drawing up specifications and bills of quantities, and inviting tenders before commencing any construction work—was out of the question. Some method had to be devised to telescope all these phases, permit work to proceed on the site as soon as any drawings were ready, be flexible enough to cope with changes of plan, confine construction responsibility into as few watertight compartments as possible; and yet, subject only to the over-riding limitation of time, to be financially economical.

The severely restricted working space on the site dictated that the number of general building contracts must be small, allocated to main areas and not to individual buildings.

Large areas (Fig. 4, Plate 2) had already been allotted for working space to the River Wall and Concert Hall contracts, both of which were planned to extraordinarily tight schedules to ensure timely completion.

Five cardinal points stood out:—

(a) Three-quarters of the site lay between County Hall and Charing Cross Bridge and three-quarters of the value and volume of building work had to be done in this, the "upstream" area.

(b) The Dome of Discovery alone accounted for nearly 30 per cent. of the whole of the building work in the upstream area. If it was to be completed by the end of 1950, together with the four other large buildings surrounding it, it was essential to begin work on it without delay.

(c) It would not be possible to start construction of the group of buildings at the north-west extremity of the site until almost the end of 1950 because this part of the site would not be reclaimed by the River Wall until then.

(d) A group of smaller buildings was to be erected in the immediate vicinity of the Concert Hall, all within the working space already allotted to it.

(e) The Bailey Bridge was to be assembled on and launched from the site. Worse than this, the largest restaurant, the Regatta, formed the bridge terminal. The bulk of this three-storey building would have to wait till the bridge was in position and work on the bridge could not start until the River Wall had progressed beyond Charing Cross bridge.

(The Design Group had foreseen these difficulties to a remarkable degree. Thoughtful emphasis was given to them in the briefing of the architects. For example, it was not overlooked that perhaps only 4 months would remain for erecting the Thameside Restaurant and adjacent structures at the north-western corner of the site.)

It was evident that the difficulties of site congestion could best be surmounted, and overall progress best served, if the contractors already working on the River Wall and the Concert Hall were willing and able to undertake the Exhibition buildings as well. This, however, was not easily arranged. Their existing contracts, which were with the London County Council, could not be extended, since the Council was not to be responsible for the building work.

The Finance Department of the Festival Office agreed to do its best to get an early clearance on the matter of letting a contract of some kind ; and the London County Council cleared the way, not without understandable misgivings, by agreeing to negotiations being opened with their contractors. The negotiations resulted, in July, in a general contract being awarded to Richard Costain Ltd, for building work on the upstream portion of the site. On the 26th of that month, almost exactly 99 years after the contract for the Great Exhibition Building of 1851 was let, work on the Dome foundations began. Later in the year the two other building contracts were awarded : to Holland & Hannen and Cubitts Ltd for the buildings around and behind the Royal Festival Hall ; and to Kirk and Kirk Ltd for the remaining group adjacent to Waterloo Bridge.

The three contracts were practically identical in form. Before award,

the following items were negotiated and agreed (in the case of Kirk and Kirk's contract they were tendered for in competition) :—

(a) The percentages for head-office overhead charges and for profit to be added to all rates and prices subsequently to be fixed, on the basis of estimated net disbursements, for work done directly by the contractor.

(b) the percentage for superintendence and profit to be added to the net cost of all nominated subcontracts.

After award, but as far as possible before the work or any substantial volume of it was done, rates and prices were agreed for each and every type of work to be done by the contractors' own site organizations. Each rate or price was assessed net, percentage (a) being added. Thereafter, for all similar work, these rates held good. Nominated subcontracts were awarded, normally by competitive tender, for all specialist work. In this way much time was gained for proper designing of, tendering for, and manufacture of shop-prepared materials.

About 600 subcontracts for supply and erection and some 350 for supply only were awarded—the great majority obtained by competition. These together accounted for about 34 per cent of the total value of the work.

Schedule rates subsequently agreed for excavation, concrete, formwork, brickwork, plastering, painting, plumbing, and so on showed close agreement in the main with rates normally quoted in competition for similar work under comparable conditions.

Development of Designs

In June 1949, the first approximate technical studies and estimates of cost were prepared from the architects' sketch designs. Extracts from the report which accompanied these estimates are reproduced in Appendix II. These first estimates were in several instances much in excess of the Festival Office budgets.

The estimates and studies led to the designs being divided into three categories, namely, those which could proceed without significant change ; those which required simplification or reduction in size, either on the score of cost or of complexity or both ; and those which would have to be redesigned *ab initio*.

While contract negotiations were in hand, consultations with the section architects proceeded apace. Priority for work on foundation and structural design was accorded to those buildings whose sites were, or would shortly be, available. Gradually, structural designs began to harden into working drawings on which tenders for steelwork could be invited and foundation work put in hand. The pace had to be forced all the time.

Each architect was expected to provide all the working drawings normally required of an architect, taking into account the needs of the Festival Office Design Group, Exhibition Management, Section Display

Designer, the G.P.O., B.B.C. (sound and television networks), Fire Brigade, specialist advisers on illumination, ventilation, public address systems, crowd counting apparatus, alarm signalling, and all the rest of the technical paraphernalia appropriate to a modern exhibition.

He also had to comply with the London County Council safety regulations for places of public entertainment. Although technically exempt by Act of Parliament from the need to submit plans for by-law approval, the Festival Office decided that its standards throughout the Exhibition should, where appropriate, be consistent with those prescribed for normal buildings.

In the early stages of design it was a rare event to be able to reach any single decision of importance that was not in some way conditional on other factors as yet undecided. Every decision was influenced, and indeed governed, by the imperative prerequisite that construction progress should not be impeded.

At this stage two committees were formed to co-ordinate requirements:—

South Bank Works Committee, under the chairmanship of the Director of Architecture and consisting of the co-ordinating architects, the engineers, and other Festival Officers, to co-ordinate the multiple and often conflicting needs of the Exhibition itself. This committee was concerned only with Festival Office matters; and it issued general directives to the section architects.

South Bank Co-ordinating Committee, under the chairmanship of the Chief Engineer, London County Council, and attended by representatives of the interested departments of the L.C.C., the Railway Executive, London Transport, Chief Engineer, London District H.Q., and the Festival Office, including their engineers, to resolve problems of occupancy of the site and surroundings as between those responsible for the various works.

Table 2 sets out the principal works on the site and will give some indication of the amount and intricacy of co-ordination involved.

Construction

In October 1949, the first tentative outline construction programme was drawn up (see Appendix III). This was in no sense a progress schedule; too little was still known of the details. Its purpose was to emphasize the periods *available* for construction. Later, comprehensive progress schedules were worked out for each building. But they were of limited value because even then the information from which they were prepared was incomplete and many gaps had to be filled by guesswork.

Target dates were fixed for completion of all architectural working drawings. These ranged, except for the two competition subjects, from the 30th November, 1949, to the 31st March, 1950. The actual events

TABLE 2.—PRINCIPAL WORKS ON SOUTH BANK SITE

Item	Owner
New River Wall..	London County Council
Royal Festival Hall	do.
New escalator, Waterloo Underground Station	London Transport Executive
Exhibition Buildings	Festival of Britain, 1951
Exhibition site works	do.
Exhibition display construction	do.
Main electrical distribution ..	do.
Bailey Bridge	London County Council
River landing stages	do.
Widening of York Road ..	do.
York Road — Waterloo Road roundabout	do.
Hungerford footbridge extension	Railway Executive, Southern Region
Victoria Embankment Platform	London County Council

were very different. Of a total of 6,200 architectural and engineering working drawings issued to the contractors (not including very many contractors' and subcontractors' drawings approved) :—

830 (13 per cent) were issued up to 31 Dec., 1949.
1,950 (31 ,,) ,, ,, between 1 Jan. and 30 June, 1950.
2,140 (36 ,,) ,, ,, ,, 1 July ,, 31 Dec., 1950.
and 1,280 (20 ,,) ,, ,, after 1 Jan., 1951.

It is not surprising, therefore, that as time went on the schedules had to be drastically revised and frequent frustration and disappointment endured. As already mentioned, the building contracts were later extended to include much interior decoration and finishing work, and also certain display construction and " landscape " work.

As soon as construction got under way, regular meetings began to be held on the site. The Chair at these meetings was taken by the co-ordinating architect for the area under discussion. This ensured that authoritative instructions were given to the section architects, whenever it appeared that progress at any point was in jeopardy for want of working drawings, specifications for specialist work, etc. Conversely it gave each section architect proper opportunity to emphasize reasons for design delays outside his power to control. The co-ordinating architect, as Festival Office representative, was thus promptly made aware of such matters and could take responsible action to clear them.

Besides the architects, engineers, and general contractors, all other interested parties attended. A period was allotted to each separate building zone. The general contractors and all specialists brought out very frankly all points, whether of supply, procedure, sequence, or design, which each considered would help towards successful accomplishment. No matter

was considered too trivial with this aim in view. A mass of tedious correspondence was eliminated. Constructive suggestions were frequent and well received. The meetings were exceptionally effective because all concerned acted promptly on the decisions made there.

About the middle of 1950, it was anticipated that, as the climax approached and with the main organizations of building construction, main services and surfacing, display and management (these last two directly under departments of the Festival Office) all simultaneously working at high pressure on the site, sufficiently rapid decisions would not be forthcoming in the absence of a single executive charged with over-riding authority and no other responsibilities. Mr Howard Lobb, who, as already mentioned, was chairman of the Architecture Council, was therefore appointed Controller, South Bank Construction. By this appointment cordial relations were maintained and numerous potential sources of delay eliminated.

There was a contractual separation between display and building work; provisional occupancy dates for the beginning of display construction had to be fixed in February 1950. Complete occupancy of whole buildings could not in many instances be given because of the additional work which meantime had been entrusted to the building contractors, and because of unavoidable delays which had occurred. Consequently a system of partial stage-by-stage occupancy was devised. This incorporated safeguards to take care of the different ways and conditions of working as between building and display trades.

Fig. 5 shows graphically the relationship between issue of working drawings, strength of labour force, and value of work done, throughout the 20-months construction period. The final peak of the labour force graph is eloquent evidence of the volume of last-minute additional work entrusted to the contractors, whose site organizations were by that time able to take this extra burden in their stride.

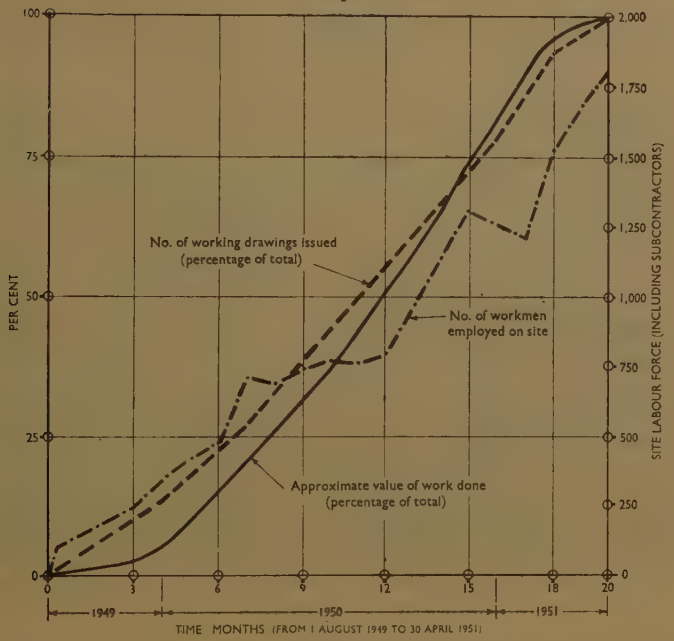
Building work close to the river, and especially between Charing Cross and Waterloo Bridges, was greatly facilitated by the completion of the River Wall more than 3 months ahead of schedule, a notable achievement. (See *Fig. 12*.)

The Bailey Bridge also was completed about 6 weeks ahead of schedule, gaining valuable time for the work to be done in the adjacent area.

Countless problems of every kind were encountered, keeping those responsible for progress in a perpetual state of anxiety. Carefully laid plans continually had to be changed to meet some new development or crisis. The fact that the Exhibition opened complete on time was due to the persistently keen and good-humoured way in which all concerned worked together and particularly to the tenacity of purpose, understanding and willingness shown throughout by the staffs of all the Contractors and subcontractors.

Fig. 6 shows the site observed from the air before the war. *Fig. 7*

Fig. 5



Relationship between Issue of Working Drawings, Strength of Labour Force, and Value of Work Done, during Construction Periods

was taken in June 1948 and shows clearance started; whilst in *Fig. 8*, (March 1949) the river wall construction has begun and clearance is well in hand. *Figs 9* to *15* indicate progress on the building work from August 1949 to April 1951; and *Fig. 16* shows the Exhibition about a week after it was opened in May 1951.

Brief Notes on Some of the Individual Structures

Fairly full descriptions of all the buildings and their details have appeared in the technical press. The following notes are included merely to place on record here selected features of engineering interest.

Waterloo Station Gate

This was a three-storey building, with steel framework and pre-cast concrete floors. The main feature was the arched shelter roof. Five two-hinged arches of laminated timber sprang from ground level, structurally independent of the building framework. Stressed-skin plywood panels connected and braced the arches together and formed part of the cover. The arches were a notable example of laminated wood construction

and in themselves were an Exhibition feature. From them was suspended a curved glazed roof with a light-alloy framework.

Information, Post Office, and Fairway Café

The main features here were :—

(a) *A screen 60 feet high and 300 feet long.*—This was of welded tubular steel construction with all panels filled with canvas sails. Consequently it had to resist a considerable wind load. Beneath the screen was an open terrace which the architect desired to be raised above the general level. Advantage was taken of this to form a cellular box footing filled with rubble to afford the necessary base resistance to overturning.

(b) *The Fairway Café roof.*—This was an open grid of pre-cast concrete members, post-stressed. Thus an area 60 feet by 40 feet was covered without intermediate supports by a flat structure with a depth of only 15 inches.

Natural Scene and Country Pavilion

The structure of this Pavilion was very simple, of steel columns, beams, and Dutch-barn roof units. Yet the architect used these with ingenuity to form a spacious and interesting construction.

Power and Production Pavilion

In this the wall and roof structures were wholly made from steel tubes and rods with welded connexions. The roof and part of the walls were of asbestos cement sheets specially moulded to shapes required by the architect. Other walls were of pre-cast concrete slabs with exposed broken-brick aggregate. The suspended galleries were formed by placing very thin pre-cast concrete units containing the appropriate tension reinforcement and pouring the remainder of the slabwork on these.

Sea and Ships

The architect conceived this " building " to create the impression of an amalgam of the innumerable forms of structure sensed in shipyards and shipbuilding. Consequently it incorporated many kinds of structural components which in normal buildings have isolated functions. It contained welded portals, steel Lamella roof, flat roofs, a suspended dome, cantilevered staircases, and normal beams and columns, all linked by a grid of light lattice-work.

Transport Pavilion

A striking feature of this building was the ingenuity used to obtain extensive areas of glass without unsightly supporting framework behind it.

Fig. 6

THE SITE BEFORE THE WAR

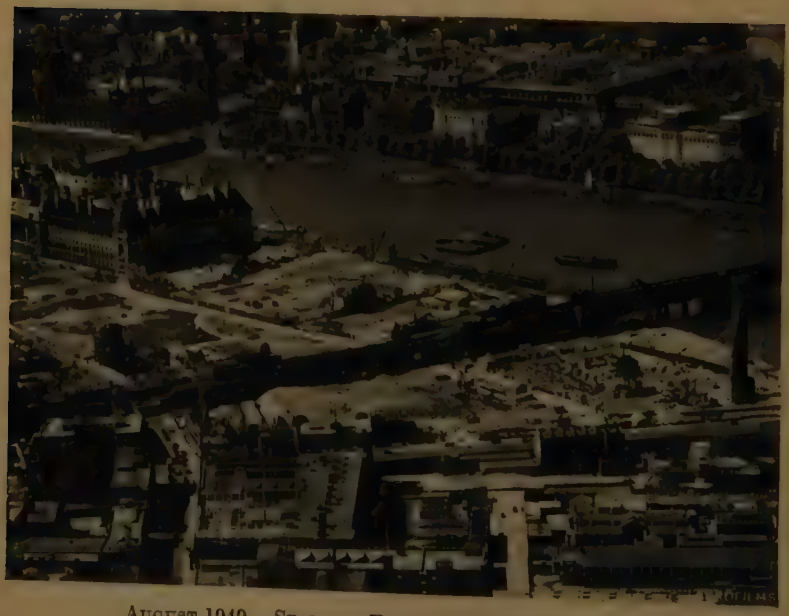
Fig. 7

JUNE 1948. CLEARANCE STARTED

Fig. 8

March 1949. River Wall Started

Fig. 9



August 1949. Start of Exhibition Building Work.
Rubble Dump being Cleared Off Dome Site

Fig. 10

May 1950. Twelve Months before Completion

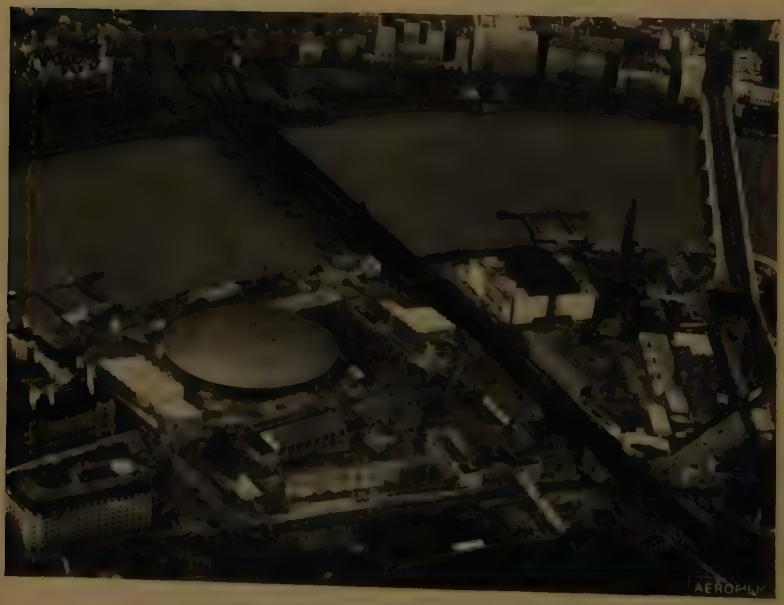
Fig. 11

August 1950. Nine Months before Completion

Fig. 12

October 1950. Six Months before Completion

Fig. 13



February 1951. Ten Weeks before Completion

Fig. 14

March 1951. Five Weeks before Completion

Fig. 15

May 1951. Two Days Before Completion

Fig. 16

MAY 1951. EIGHT DAYS AFTER COMPLETION

Regatta Restaurant

This was a relatively heavy three-storey building containing a large basement pumping station (for the main fountains). Its site was wholly over the area to be reclaimed behind the new river wall and thus did not exist until February 1950. It was not permissible to load the ground immediately behind the wall. Therefore the foundation scheme incorporated beams to span from more shoreward footings on to the wall directly. Moreover, since the Bailey bridge terminated on the building and had to be assembled on and launched from the same site, the construction programme had to include an idle period of more than 3 months while the bridge was being built. To facilitate progress on both bridge and building, the foundations of the latter were constructed rapidly and incorporated foundations for the very heavy loads which would be imposed by the bridge-launching platform. Consequently the speed of completion had to be exceptional, especially having regard to the very great amount of detail work required in this important building. It contained a high-quality restaurant with appropriate finishes and Press accommodation for the entire Exhibition.

The Skylon

Model-experiments in a wind tunnel provided three interesting results, namely :—

(a) the wind loading upon the twelve-sided louvre-clad framework was almost exactly the same as that on a solid cylinder of circumscribing diameter ;

(b) they indicated the minimum tension that should be introduced into the supporting cables to ensure aerodynamic stability of the structure ;

(c) that the wind loading to be used for design of this particular structure should be about 1·6 times that produced by a steady wind of the assumed maximum velocity, to allow for the dynamic or " impact " effect of recorded gust accelerations.

Another interesting feature is that all the cables were pre-stretched and socketed to precise calculated lengths with no direct means of adjustment, thus avoiding clumsy fittings on them. Tensioning was effected by jacking upwards at the feet of the three inclined struts. Permanent means for doing this were provided below ground level, out of sight.[3]

The Dome of Discovery

The Dome roof itself has already been described. But under the cover of this roof were three principal raised galleries at 12, 22, and 35 feet above ground floor with a total area of some 42,000 square feet, all structurally independent of the Dome shell. (*Fig. 10.*) The uppermost gallery was served from ground floor by an escalator spanning from bottom to top without intermediate supports, the slope length being 170 feet.

The Telecinema

This was near the Charing Cross Railway Bridge. The walls and floor of the main auditorium were below ground level and were constructed of reinforced concrete. All formed a tanked raft foundation " floating " in the soft clay.

For sound insulation, the walls and roof were of heavy solid construction with appropriate detached linings inside and out.

The balcony was of steel framing carrying pre-formed dovetail sheeting ; the latter material was incorporated in the structure of the roof. The screen end of the building was formed as a complete prefabricated unit out of dovetail sheeting and light steel framing.

The Lion and the Unicorn Pavilion

The walls had a structural steel frame ; the roof was of Lamella construction of oak and plywood ; and the cladding, where not of glass, was of rendering on metal mesh.

Homes and Gardens

The structure of this building used, to a great extent, steel scaffold tubing. For main trusses the tubes were welded together with small gussets and formed a neat arrangement with subsidiary connexions and bracing using scaffolding connectors.

The building known as " Introduction to Homes and Gardens " was the only one wholly clad with canvas. The main framework was of very light lattice portals to which were attached horizontal and vertical rails forming panels. The canvas was stretched over light frames which were shaped to deform the canvas out of plane and thus prevent it from flapping.

The Sea-side Section

This was a " live " structure in the sense that the large velarium in combination with the platforms extending over the River Wall depended for stability on wire rigging.

The platforms, which at times were as heavily loaded with people as they could be, had stressed helical springs beneath them to ensure that, when the platforms were so loaded, extension of the ropes would not engender a feeling of instability.

This structure extended along the river bank on a curve ; because of that the calculations for setting out and lengths of ropes to satisfy the architect's rigid requirements for the inclination of struts and their uniformity, were more onerous than the structural design.

Shot Tower

The Shot Tower is of brickwork 3 feet 6 inches thick at the bottom and 1 foot 10½ inches thick at the top. The mortar is very soft and the dead

load stress in the brickwork at the bottom was of the order of 8 tons per square foot.

Two door openings were carefully cut through it near its base as part of the display requirements. After taking down about 15 feet at the top, a steel structure, about 50 feet high and of a shape dictated by the architect's design, was erected to carry a lighthouse lantern and the radar telescope. This latter was mounted on the barrel casing of a more or less complete 3·7-inch anti-aircraft gun (so that its motion could be actuated by remote control from the Dome of Discovery) above the lantern, about 200 feet above the ground.

The 35-foot diameter radar telescope reflector was erected on the ground with its axis vertical, and then turned and suspended with its axis horizontal. A jib of steel scaffolding was erected on the steel structure above and the reflector hauled up to a predetermined height and the jib luffed to bring the reflector in towards the gun.

Because of the delicacy and value of the reflector and its aerial and its large wind-catching area, the lifting arrangements had to be carefully studied; but the whole operation of lifting and fitting on to the gun was accomplished in 20 minutes.

Thameside Restaurant

The main feature of this structure was its corrugated shell roof. It consisted of a sandwich of two layers of 20-gauge aluminium alloy sheet separated by a layer of cork 2 inches thick, and taking the form of a continuous sine wave.

Waterloo Bridge Gate

This contained turnstiles, and entrances and exits from and to Waterloo Bridge Road. It was constructed mainly in orthodox reinforced concrete with light metal and asbestos-cement shelter roofs. Surmounting the building was a viewing tower of open steel frame construction housing a glass-enclosed lift.

Post-tensioned Footbridge

This bridge had four continuous spans of 76, 58, 76, and 54 feet, and a 19-foot cantilever.

To meet site conditions a 76-foot span and 27-foot cantilever were first constructed. A second similar cantilever and span were constructed later together with the remaining span and permanent cantilever, the whole deck being stressed by continuous cables.

Alternate columns were initially hinged near the base and at the head to take up shortening of the deck due to stressing. The deck was 12 feet wide with a maximum thickness of 1 foot 10 inches giving a depth/span ratio of 1 : 43.

The columns had single cables in grooves on their side faces; these

cables passed into the deck above and were tensioned after all the column hinges had been packed with stiff concrete.

B.B.C. Building

This, although not an Exhibition building, had sound-insulating construction and all the very intricate building requirements of the B.B.C.'s equipment.

Lessons

The Authors consider that the design and construction of the Exhibition Buildings has brought forth few significant advances in engineering technique and economics. On the other hand, it may well be that many valuable architectural lessons have been learnt ; and it is to be hoped that these may extend beyond the field of exhibition design alone.

Many truths were, however, emphasized anew ; among these the following may be mentioned :—

In modern building, collaboration between architect and engineer should begin at the very inception of the design.

For rapid and economical construction, drawings and specifications must be complete and concise down to the smallest detail. The contractor should not be blamed for mistakes arising from ambiguous or inadequate instructions.

Where design and construction must proceed simultaneously it is dangerous to base a rigid organization on a detailed progress schedule prepared in advance. Real progress demands flexibility, a readiness to appreciate other people's difficulties and, above all, absolute mutual confidence between architect, engineer, and contractor.

At negligible extra expense, the architects made greatly effective use of colours on ordinary materials such as steel, asbestos, and concrete, so often left drab in industrial buildings. Engineers would do well to note this, and also the careful thought and attention given to well-shaped details and connexions, balustrade fixings, staircases, and concealment of ugly rainwater pipes and the like.

Quantities

A total of 2,800 tons of structural steel was used in the main building frameworks ; 41,000 cubic yards of concrete were poured on the site ; and 9,700 tons of cement were consumed.

The aggregate covered ground-floor area of all the buildings (excluding approximately 60,000 square feet under existing arches) was 360,000 square feet and of raised floors 220,000 square feet. Of the total of 580,000 square feet, 394,000 square feet was Exhibition space.

Personnel

Of the Authors, Sir Hugh Casson was Director of Architecture in the Festival of Britain Office, and Co-ordinating Architect for the " downstream " area of the site. Messrs Freeman, Fox & Partners, in association with Messrs R. T. James and Partners, were the Consulting Engineers for the Exhibition Buildings, Mr Freeman and Mr James being the partners mainly responsible for the works described in the Paper.

Mr Misha Black, O.B.E., and Mr Ralph Tubbs, O.B.E., were respectively the Co-ordinating Architects for the " upstream " area and the Dome area ; Mr James Holland, O.B.E., and Mr James Gardner were the Co-ordinating Display Designers. These four gentlemen and one of the Authors (Sir Hugh Casson) together constituted the Design Group, referred to in the Paper.

The names of the individual building architects and of the other engineers concerned with the buildings are given in Table 1.

The Chief Engineer, London County Council, was responsible to the Festival Office for the general levelling of the site, water and gas mains and main drainage, and most of the paved areas.

Messrs McLellan and Partners were the Consulting Engineers for the main electrical distribution system, transformers, and switchgear.

On the building work Mr L. S. Adlard was Resident Engineer, assisted by Mr F. G. Deveney in charge of electrical and mechanical work.

The general contractors' chief personnel on the works were as follows :—

Richard Costain Ltd

Agent	Mr W. D. Mulholland, M.B.E.
Chief Assistant . ..	Mr J. P. Sowden
Chief Surveyor	Mr E. A. Arblaster
General Foreman	Mr G. A. W. Hicks, B.E.M.

Holland & Hannen and Cubitts Ltd

Agent	Mr J. J. Ryan, M.B.E.
Chief Assistant	Mr H. H. Humble
Chief Surveyor	Mr A. J. Gozzett
General Foreman	Mr S. L. Cornwell

Kirk & Kirk Ltd

Agent	Mr R. Turvey
Chief Surveyor	Mr C. H. Woodward
General Foreman	Mr G. F. W. Thompson

Acknowledgements

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Mr G. A. Campbell (Festival of Britain, 1951)
Mr Richard Miles („ „ „)
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Mr Leslie Gooday
Mr C. Wycliffe Noble
Mr I. L. Williams
Mr L. R. Cutbush
Mrs A. Brunsdon
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The Authors wish to record sincere appreciation of the work done by their partners and by members of their staff, practically all of whom were at some time engaged on this project.

Finally they wish to record their indebtedness to the late Sir Ralph Freeman. It was his far-seeing judgement, confident guidance, and initiative, coupled with his high standing in the profession that paved the way and enabled the project to be carried through to its successful completion.

References

1. E. O. Measor and D. H. New, "The Design and Construction of the Royal Festival Hall, South Bank." J. Instn Civ. Engrs, vol. 36, p. 241 (May 1951).
2. Gilbert Roberts, "The Structural Design of the 'Dome of Discovery,' Festival of Britain 1951." J. Instn Civ. Engrs, vol. 36, p. 377 (Oct. 1951).
3. F. J. Samuely and P. J. A. Ward, "The Skylon." Proc. Instn Civ. Engrs, vol. 1, Part I, p. 444 (July 1952).

The Paper is accompanied by eleven photographs and five sheets of drawings, from some of which the half-tone page plates, folding Plates 1 and 2, and the Figures in the text have been prepared, and by three Appendices.

Appendix I

EXTRACTS FROM CONSULTING ENGINEERS' LETTER OF APPOINTMENT

"I ..... appoint you as Supervising Engineers for the construction of the South Bank Exhibition to provide the following services :—

"The general levelling of the site, construction of roads, ... main drainage ....., drainage of large paved areas, ... electric mains, ... gas and water mains ..... will be undertaken by or under the supervision of the London County Council. The Council have agreed to co-operate with you to ensure that essential facilities are available to the Building Contractor and that neither the ..... operation of the Festival Office nor those of the ..... Council are delayed.

"You will be required to supervise the construction of a number of buildings ..... The buildings will include the foundations and floor slabs, the superstructure and decorative treatment of the superstructure, but not internal fittings and internal decorative treatment. You will be required to organise construction work on the whole site; to prepare all necessary drawings for structures and foundations based on the Architects' designs; to carry out negotiations with Government Departments, the London County Council and other authorities concerned; to report ..... on progress and proposals for construction; to consider Architects' designs and to advise them regarding construction conforming to their requirements; and to provide all necessary services ..... to ensure that the works are carried out rapidly and economically and are completed by 30 November 1950.

"You will be required to submit proposals for the letting of contracts for construction and for controlling the execution of the construction by contractors. ..... you will be required to measure and certify contractors' claims for payment."

Appendix II

EXTRACTS FROM REPORT ACCOMPANYING FIRST APPROXIMATE ESTIMATES OF COST

The sketch designs ..... have only been submitted to us within the last week or two and provide little definite information both as to construction and details. It has been possible for us to form our estimates only on broad generalisation .....

..... we recall that when this project was submitted to us we understood that designs would be of a simple character based on the use of materials not commonly employed; canvas and cement mortar on fabric forming a simple arched shape were specially mentioned; neither has been employed to any significant extent.

..... there is, in our judgement, a very grave risk that the aggregation of buildings of the type portrayed in the sketches submitted to us cannot be completed in the time allowed (i.e. by the end of November 1950).

Appendix III

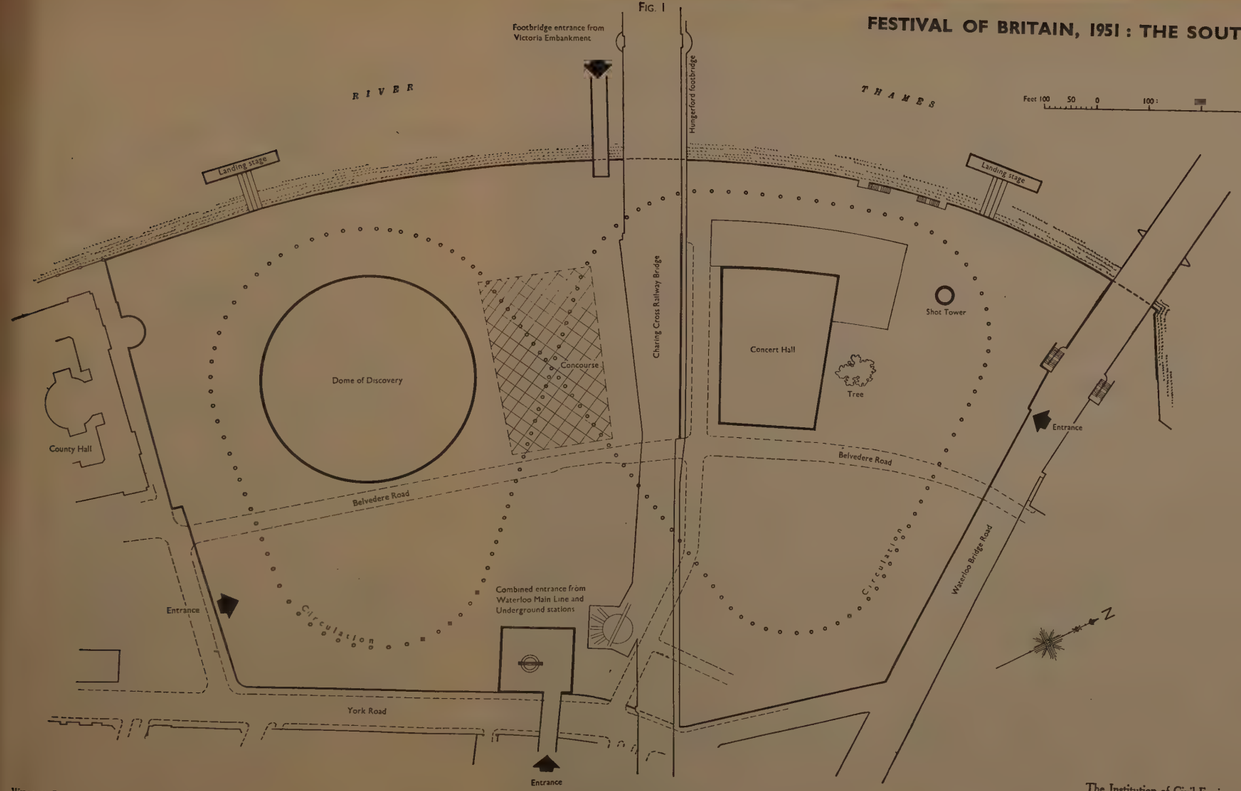
Tentative construction programme—October 1949

with actual dates of starting and substantial completion added in italics

Ref. No. on Fig. 3, Plate 2	Building	Starting date	Completion date	Remarks
1	Station Gate and Police Block .	1/1/50 (*1/12/49*)	14/1/51 (*30/4/51*)	Start contingent on programme for L.T.E. escalator contract. Completion contingent on demolition of " The Rising Sun " as agreed.
2	Information and Post Office . .	15/10/49 (*15/10/49*)	31/1/51 (*30/4/51*)	
6	Minerals of the Island	1/10/49 (*1/10/49*)	31/8/50 (*30/9/50*)	
7	Management Offices	15/3/50 (*15/2/50*)	31/10/50 (*28/2/51*)	
8	Natural Scene and Country . .	15/9/49 (*1/9/49*)	30/9/50 (*15/2/51*)	
9	Power and Production . . .	1/11/49 (*15/11/49*)	28/2/51 (*31/1/51*)	Contingent on part of site at present reserved for River Wall contract till 31/12/50 being made available without impeding progress on River Wall.
10	'51 Bar	1/3/50 (*1/10/50*)	30/11/50 (*30/4/51*)	do. do.
12	Sea and Ships	1/1/50 (*15/1/50*)	30/11/50 (*31/12/51*)	Start contingent on anticipated progress of River Wall contract.
13	Skylon	1/3/50 (*15/9/50*)	30/11/50 (*15/4/51*)	do. do.
14	Regatta Restaurant, etc. . . .	1/3/50 (*1/3/50*)	31/3/51 (*15/4/51*)	Depends on release of site from River Wall contract and on progress schedule for Bailey Bridge.
17	Transport	15/11/49 (*15/12/49*)	18/2/51 (*15/3/51*)	Depends on space required for erection of Bailey Bridge.

FESTIVAL OF BRITAIN, 1951 : THE SOUTH BANK EXHIBITION BUILDINGS

FIG. 1



INITIAL MASTER PLAN

GOVERNING SITE LIMITATIONS AND PRINCIPAL DECISIONS, AUGUST 1948

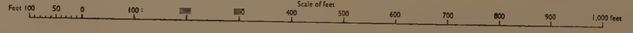
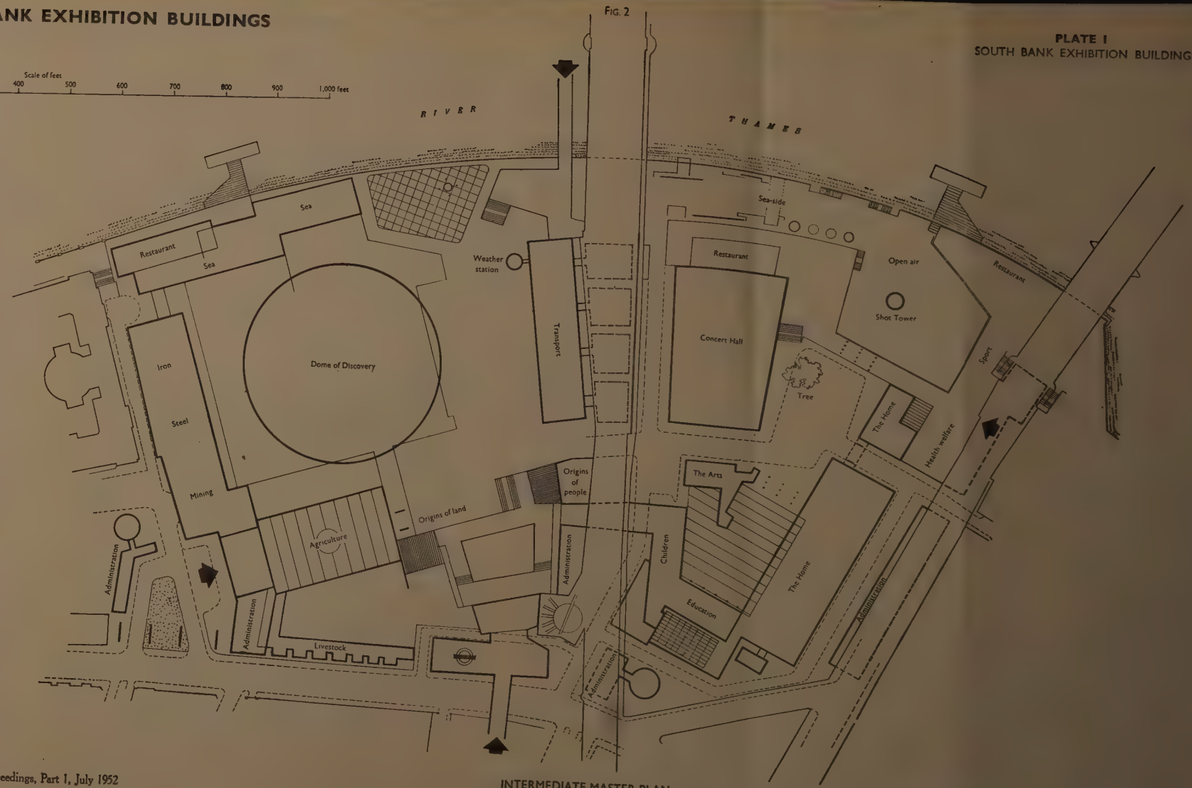


FIG. 2



INTERMEDIATE MASTER PLAN

PRELIMINARY BUILDING LAY-OUT, DECEMBER 1948

PLATE I

SOUTH BANK EXHIBITION BUILDINGS

SIR HUGH CASSON, RALPH FREEMAN, and R. T. JAMES

WILLIAM CLOWES & SONS, LIMITED: LONDON

PLATE 2
SOUTH BANK EXHIBITION BUILDINGS

FESTIVAL OF BRITAIN, 1951 : THE SOUTH BANK EXHIBITION BUILDINGS

FIG. 3

KEY

1. Station gate, Rocket Cafeteria and Police block
2. Information Offices and Screen
3. Post Office
4. Fairway Café
5. Turnstile canopy
6. Minerals of the Island
7. Management Offices and Royal Pavilion
8. Natural Scene and Country
9. Power and Production
10. 'Sí Bar
11. Water-tower
12. Sea and Ships
13. Skylon
14. Regatta Restaurant and Press Centre
15. Masts on Bailey Bridge
16. Victoria Embankment entrance canopy etc. } Not shown
17. Transport
18. Main Fairway and Fountain Lake
19. Land of Britain
20. People of Britain
21. Turntable Café
22. Dome of Discovery
23. The Lion and the Unicorn
24. Television and Telecinema
25. Introduction to Homes and Gardens
26. Homes and Gardens
27. Waterloo Bridge gate
28. Viewing tower
29. Schools and Health
30. Thameside Restaurant
31. Harbour Bar
32. Sport
33. Shot Tower
34. Centenary Pavilion
35. Boathouse, Pools and Sports Arena
36. Seaside Velarium and viewing platforms
37. Staff quarters, administration and canteen
38. B.B.C. central control and G.P.O. telephone exchange
39. Decoration of Hungerford footbridge and Sutton Walk entrance to Royal Festival Hall

FINAL MASTER PLAN
WITH LIST OF EXHIBITION BUILDINGS

FIG. 4

Reclaimed land Not available until March 1950 (See Note D)
Reclaimed land Not available until December 1950 (See Note F)
Reserved for river wall contract
Until December 1950 (See Note A)
Until March 1950 (See Note B)
Until December 1950 (See Note C)
Required for Bailey Bridge erection, March to September 1950 (See Note E)
County Hall
Site for Dome of Discovery
Concert Hall site
Reserved for Concert Hall contract until January 1951
Reserved for River Wall contract until December 1950 (See Note G)
Waterloo Bridge
Charing Cross Railway Bridge approach viaduct
Area required for erection of Hungerford footbridge extension
Reserved for Concert Hall contract
Until June 1950 (Floors, etc. Standing, etc.) (See Note H)
Until Dec. 1950 (Site offices)
Until November 1949 (Bailey bridge etc.)
Waterloo Road
Reserved for L.T.E. Escalator contract until December 1949
York Road
Site for western leg of new roundabout
Reserved for Escalator contract until December 1950
Scale of feet
Feet 100 50 0 100 200 300 400 500 600 700 800 900 1,000 feet

* Tenancies of, and rights of approach to, arches expire at various dates during 1949 and 1950. Two arches near river end will not be vacated until December, 1950)

The following changes occurred, or were agreed, later:—

A. Vacated in two parts, in Nov. 1949 and in Mar. 1950, to let Exhibition building work.
B. Part of rubble dump cleared, freeing "Dome" site in Aug. 1949
C. Vacated Aug. 1950, owing to earlier completion of river wall.
D. Became available Feb. 1950, owing to improved progress on river wall.
E. Area reduced and revised to avoid site of Transport Pavilion. Actual occupation for Bailey bridge was from end of May to mid-Aug.
F. Northern end of this area became available Sept. 1950, owing to earlier completion of river wall.
G. Area curtailed and start of occupation by river wall contract deferred until Apr. 1950. This enabled main platform of Waterloo Bridge gate to be built first.
H. Area curtailed to free sites for "Lion and Unicorn" and "Homes and Gardens" pavilions

AVAILIBILITY OF WORK SITES, APRIL 1949

SIR HUGH CASSON, RALPH FREEMAN, and R. T. JAMES

The Institution of Civil Engineers Proceedings, Part I, July 1952

WILLIAM CLOWES & SONS, LIMITED: LONDON

APPENDIX III—(*continued*)

Ref. No. on Fig. 3, Plate 2	Building	Starting date	Completion date	Remarks
19	Land of Britain	15/11/49 (*15/1/50*)	31/8/50 (*31/10/50*)	
20	People of Britain	1/1/50 (*1/11/49*)	30/9/50 (*31/12/50*)	
22	Dome of Discovery	15/8/49 (*1/8/49*)	28/2/51 (*15/2/51*)	
23	Lion and Unicorn	1/12/49 (*1/6/50*)	30/9/50 (*31/12/50*)	Depends on diversion of Sutton Walk.
24	Television and Telecinema	1/12/49 (*15/1/50*)	31/10/50 (*28/2/51*)	
26	Homes and Gardens	15/11/49 (*15/1/50*)	31/10/50 (*31/12/50*)	
27	Waterloo Bridge Gate	1/11/49 (*1/12/49*)	31/12/50 (*30/4/51*)	Area under platform to be completed and handed over to River Wall contractor for working space by 31/3/50.
29 & 32	Health, Schools, Sport	1/1/51 (*15/3/50*)	31/3/51 (*15/12/50*)	It is hoped that River Wall contract will be completed before 31/12/50 and allow earlier start on these buildings.
33	Shot Tower and surroundings	(*15/3/50*)	(*30/4/51*)	Work to be done during 1950 to suit progress on Concert Hall.
36	Seaside	1/1/51 (*15/1/51*)	31/3/51 (*30/4/51*)	See remarks against Health, Schools, Sport.
37	Administration and Staff Canteen	1/1/50 (*1/2/50*)	31/1/51 (*31/1/51*)	Depends on programme for York Road—Waterloo Road roundabout.
38	B.B.C. Central Control and G.P.O. Telephone Exchange	(*15/9/50*)	(*15/2/51*)	(Not included in tentative programme.)

Discussion

The Authors introduced the Paper with the aid of a series of lantern slides.

Mr F. M. Fuller observed that in paragraph (3) on p. 350 the function of the architect had been summed up very neatly—" To brief the architects as carefully as possible and to leave them alone to develop their designs." He had often wondered whether each individual architect had not been left alone too long or too much, because, in listening to architects discussing those buildings, one architect had assured him that one building was complementary to another, and the next architect had assured him that the buildings acted as a foil to each other. He did not pretend to understand it, but possibly Sir Hugh Casson would comment on that.

On p. 356 he thought that there was a misunderstanding with regard to the water levels on the site, which were stated as being about + 7·00 O.D. In actual fact, as shown by numerous borings made on the site, the average water level was approximately O.D., and varied a foot or two on either side with the tide. It was possible that the figure of + 7·00 had been given through confusion arising from the fact that after very heavy rainfall the water in the sewers surcharged to that level, but that bore no actual relationship to the subsoil water level under the site.

Reference had been made in the Paper (p. 356) to the filling behind the river wall. That had been consolidated by means of bulldozers, not by heavy rollers. Very effective consolidation had been obtained, as was shown by the deep trenching which had been dug immediately afterwards, when it had been found that the sides could stand vertically without any shoring or strutting.

In the last paragraph on p. 356 the Authors had stated: "It was decided in general to use steel frameworks, with bolted joints for speed of erection and ease of dismantling." Mr Fuller had often wondered why that principle had not been applied to the Minerals of the Island building, not only for ease of erection, but because it would now present considerable problems in demolition. His general impression of all the buildings in the upstream area was that sufficient regard had not been paid to the fact that they were being erected for 1 year only, or, as some optimists thought at the time, possibly for 2 years, since the Exhibition might, it had been thought, remain open for a second year. In going over those buildings, he had been led to doubt whether very many alterations would be required had they been built to last for many years.

On p. 359 details were given of the method of negotiating contracts for the Festival of Britain, and on p. 361 there was a list of contracts. It should be emphasized that the majority of the contracts listed on p. 361 —the majority in number, though not necessarily the greater part in value—where the owner was given as the London County Council, and

he believed also where the owner was the Railway Executive, had been let after the receipt of competitive tenders, and did not come under the system described by the Authors.

On p. 360 reference was made to the working committees. In the case of the second of these—the South Bank Co-ordinating Committee—which was under the chairmanship of the Chief Engineer of the L.C.C., Mr Fuller had just looked through the Minutes and found that that Committee had held sixteen main meetings from 28 April, 1949, to 16 March, 1951, and many more sub-committee meetings. Typical of the points discussed were : the possibility of having a moving platform on the Bailey Bridge ; the possibility of using screw piling instead of timber piling for the Bailey Bridge piers (because the architects thought it would make a more artistic job) ; the allocation of working areas between the various contractors (a continual subject of discussion) ; the progress of demolition on the site ; and so on.

He was very pleased that the Authors had mentioned the good progress made with the river wall, which had been finished three months ahead of schedule. He would like to add his own tribute to the contractors engaged on that job for the successful and speedy conclusion of the work. In conclusion, he would echo Mr Freeman's comments on the co-ordination between the architects and the engineers. They had not always seen eye to eye, but they had always agreed to differ very pleasantly, and, he believed, without any detriment to the work.

Mr Howard V. Lobb observed that when the programme had first been drawn up, it had required the Exhibition pavilions to be ready for the display contractors, with the whole of the general contractors' work completed, by the end of November 1950. When it had become apparent, for various reasons, that there would be delay, an extension of that time had been possible owing to several factors. The first, and probably the most important, was that the display contractors themselves had been either unwilling or unable to start work so early. Secondly, it had been found that the display contractors could work side by side with the main contractors. A particular example of that was in the Power and Production building, where certain advantages accrued—although there were difficulties as well—from having the display contractors working alongside the general contractors. In other buildings the time limit could be extended because no display was included in the programme. That applied to such buildings as restaurants, lavatory blocks, and so on.

Mr Fuller had commented on the question of temporary construction, and reference was made in Appendix II to the first thoughts of the Design Group in connexion with the construction of the buildings. A detailed investigation of some of the temporary methods of construction had proved them to be more expensive than other methods. Furthermore, the buildings had had to withstand a full winter, with rain and snow loads, and a period of summer when there was a considerable amount of rain, and so

those temporary forms of construction had not been practicable. Mr Lobb thought he was correct in saying that the one really temporary building, which had been called the " pantechnicon," attached to the Homes and Gardens building, which had canvas walls and a canvas roof, had been more expensive than if it had been constructed in the normal permanent construction.

There had been, of course, another requirement which he was sure that Mr Fuller, from his association with the London County Council, would have in mind. Due account had had to be taken of the fire-resisting standards required for a considerable width on each side of Hungerford Bridge, and also round the public entrances and exits.

In accordance with Government policy, competitive tenders had had to be invited whenever that was a practicable possibility, but in many cases it had been a difficult matter for the consultants to find steel firms who would undertake the job of fabrication and erection in the very short time available. On some contracts a considerable amount of time, which could be ill-afforded towards the end of the job, had been taken up by the normal Government procedure of obtaining three or four tenders. On rush jobs of the kind in question, that brought the whole question of competitive tendering into doubt, because the time thus wasted had to be made up in overtime, so that he doubted whether any appreciable saving had been obtained from the competitive tendering process.

No mention had been made in the Paper of the budget reviews in July and December of 1949 and July of 1950. The effects of those reviews, particularly on the Authors and on the architects generally, had been a contributory cause to some of the delays in completion. Revisions had been made from time to time in the theme of the Exhibition. By far the greatest single cause of delay, however, was the appalling weather in the winter of 1950. The weather was a favourite subject of conversation among Englishmen, and it might be of interest to record that that February had been the wettest for 81 years. In a period of 7 months prior to the opening of the Exhibition, one-fifth of the total working time had been lost because of bad weather. Nevertheless, in spite of all those difficulties, the Dome had been handed over, as the Authors had stated, a fortnight ahead of schedule.

On the subject of site organization, some comment might be made on the special arrangements introduced towards the end of the job on the upstream section, where a special gang had been employed with a foreman and three or four lorries whose sole job was clearing up, and who had worked at night. It was found that they could move about three times as much rubbish to a tip as could be done by a similar number of men and lorries employed during the day, partly because at night there were no traffic delays. The system of temporary lighting which had been installed in the buildings and on the site enabled that gang to work ; that system had also been used extensively in building operations. When the display material

had started to arrive on the site a system of one-way traffic had been instituted throughout, which had greatly helped, and with the help of the Festival Office security staff some measure of control had been secured.

Right in the middle of all the Exhibition activity there was the building of the great Royal Festival Hall, which had very often involved the bringing in of large components. The co-ordination between the Festival Authorities and the Architect and Engineer of the L.C.C. and the Contractors employed on the Festival Hall had been a model of its kind, and Mr Lobb wished to pay his tribute to that collaboration.

In an effort to combat the appalling weather conditions, towards the end of the job, steam boilers had been used to heat the aggregate, whilst tubular scaffolding framework and tarpaulins had been used to enable work to proceed which would otherwise have come to a standstill. Detailed weather forecasts had been received from the Meteorological Office at Dunstable, and they had proved to be very accurate.

He would like to comment on the organization of the job generally from the labour relations point of view. During the last 9 months of the work there had undoubtedly been a political minority who were against the whole idea of the Festival, and who had been helped by the ill-considered comment of certain newspapers which would suffer some uneasiness if accused of being Left Wing. A total of eleven strikes had occurred during the later stages, and the forms of construction and the many new materials which had been used resulted in more than fifty demarcation tribunals to sort out the responsibilities of the various trades. In many cases those disputes had involved the stoppage of work on a particular section until agreement was reached on whether the plasterer or the bricklayer, or whoever it was, should do a particular job. The solutions of some of those difficulties might be of lasting benefit in future construction.

Again with regard to labour relations, there could be no doubt that a very considerable improvement in morale on the job had been brought about by the visits paid to the site, in particular by His late Majesty King George VI, followed by various important people, ranging in status from Field Marshals to film stars—although perhaps the contractors would not altogether agree with him about the film stars. At a later stage, conducted visits of the Press and their photographs and the general raising of interest in the country had done much to improve morale. About 6 or 7 weeks before the opening day the site had been thrown open to all the workmen and their families and if Mr Lobb had been asked to name the greatest single factor responsible for getting the buildings completed to time, in spite of all the difficulties, he would say that it had been that visit by the workmen and their wives and children. The difference in morale afterwards had to be seen to be believed, and he wondered if there was not some lesson to be learned from that. He felt that, even on the smallest housing scheme, if the mayor, complete with chain of office and retinue, would pay a formal visit, see the work which was going on, and talk to the men, telling them

about the housing list and all the problems involved, there might be a better appreciation of those problems.

The various architects had interpreted their budgets differently in almost every case, and according to the theme of the particular pavilion. In the Homes and Gardens pavilion, little had been spent on the structure, which had been mainly of tubular scaffolding, which had been hired, whereas in the Lion and Unicorn building a considerable part of the budget had been spent on specialist finishes, specially designed and printed wall-papers, and so on.

In conclusion, he would underline one of the lessons learned from the job. Much had been written in the architectural and engineering press about the influence of the South Bank in the future, and the dynamic quality of the engineering design had been particularly emphasized. He would like, however, to add a word of warning. The collaboration of the engineer with the architect was obvious and would, he hoped, be accepted without question. He entirely agreed with the Authors that that collaboration should start as early as possible. The very important part played by engineering in building was, however, in his opinion apt to be exaggerated to the point where even the technicians became blind to the fact that a building structure was only a means to an end. Structure had, on the South Bank, been glorified into something which came first, but that was misleading ; it was the *building*—the plan, section, elevation, and structural realization of all three dimensions of an idea—which was, after all, of the first importance. He hoped that the technical collaboration which had been realized in the South Bank Exhibition would move forward on those lines.

Mr W. D. Mulholland observed that the Meeting had heard the engineers' version and the architects' version, and he now wished to give the builders' version of the South Bank, so far as he had seen it.* On the 25th July, 1949, their first contingent had appeared on the site, consisting of himself as agent, a general foreman, and a quantity surveyor. They had been met by the Resident Engineer, who, he believed, had been established on the site for some time. They had arrived without any drawings, and without any information about what would have to be done. The first drawing, received on the 8th August, had been an unfinished foundation plan for the Dome. On the site where the Dome was to be erected, there was about 20,000 to 30,000 cubic yards of bomb rubble. (It could be seen in *Figs 8* and *9*.) There had still been a number of buildings to be demolished.

By the 15th August, approximately 18,000 cubic yards had been removed, and a start had been made on the excavation of the Dome foundations. There had never been sufficient drawings or information on any building in advance to give the contractors a picture of what work

* Mr Mulholland was Contractor's Agent on the upstream site.

had to be done, or to enable them to organize their labour force and to order materials in advance. They could only estimate what labour force was likely to be required and order reinforcements as far as possible in advance. If they had not had a job in progress on the other side of the river, from which they could borrow a bit of reinforcement now and again, they would not have been in a position to start the foundations.

Owing to the lack of drawings, the contractors' greatest difficulty had been to plan the job as a whole, keeping in mind the early completion date for the display contractors so as to give them time to complete their work before the opening day. More than once they had received the drawings for the foundations and completed the job without knowing what was going on top of them. In fairness, however, it had to be said that the architect could not complete his drawings for lack of information from the display designer. That difficulty had never been overcome during the whole of the work, and had often caused a great deal of work to be done out of sequence.

It became apparent at an early date that, owing to the lack of architects' drawings, the contractor was going to be spoon-fed with information for the whole job, and each building would have to be treated as a separate contract. The work had therefore been organized in the following manner. Mr J. P. Sowden, their Engineer, had been put in charge of the whole job from the office point of view and had been responsible for progressing every building, for seeing that all the drawings were distributed after checking, and for chasing information which was lacking and holding up progress. He had also been at hand to answer any queries that the engineers, architects, or foremen might raise from time to time. Under him were three junior engineers, whose job was to progress the buildings and order materials after quotations had been received, chase sub-contractors, and maintain liaison between the office and site foremen. There were also four site engineers setting-out and giving levels.

Owing to the speed with which each building had to be erected and the detailed and intricate work involved, it had been decided to put a general foreman in charge of each building, with sub-foremen and charge-hands, treating each building as a separate contract. There had been an overriding general foreman in charge of all the work. That arrangement had worked very well.

All the specialized trades had had their own general foreman and staff, and included :—

Scaffolder.

Steel Bender.—All reinforcement had been cut and bent on the site.

Plasterer.—All stick-and-rag plaster and a good deal of artificial stone had been made on the site.

Plumbers.—Had had their own design department and drawings had been done on the site.

Painters.

The maintenance electricians had been responsible for all the temporary lighting. There had been a labour office for the engagement of all site labour, also an office for the trade union liaison officer whose duty it had been to settle disputes at an early stage. On the surveying side Mr Arblaster had a staff of sixteen who had been kept very busy. All progress work had been bonused and separate staff had been required for this purpose. A fully-equipped canteen, seating more than 1,000, had served the sub-contractors and display contractors as well as contractors' own men. A works committee of stewards from each of the trades, with a Federation steward as chairman, had held regular meetings every Wednesday after lunch. Mr Mulholland was the only person who had attended from the management side. Those meetings had been very useful in getting over difficulties at an early stage and preventing trouble on the site, and they had made it possible to get to know the men personally, which was very useful on any job.

Meetings had frequently been held in the early stages between the architects, engineers, and contractors to discuss problems of construction. An example was the concrete canopy over the turnstiles. Originally that canopy was to have had lattice beams underneath, but after a meeting at which costs and how the job was going to be done had been discussed it had been agreed to alter the whole scheme and leave a plain surface underneath, and it had been built in that manner.

The construction of the buildings had provided the greatest interest. Every building was different, each having its own problems. When the job had progressed beyond the foundation stage and become interesting, he believed that every man on the site had become genuinely interested in the job. In an effort to stimulate that interest the Federation steward had been invited to the architects' meetings, where he had had a chance to see the problems from the contractors' angle.

There had been labour problems, which were to be expected on a job of that size, but as the work had proceeded all the different organizations had welded into one big team, and the engineers, the architects, and every man on the site, including the sub-contractors, had become imbued with a team spirit, and that had enabled the work to be finished on time.

The engineers had done a good job in providing the detailed drawings without delay. They had not had time to post them from Victoria Street to the site, and so they had organized a shuttle service over Westminster Bridge, because the post took 2 days.

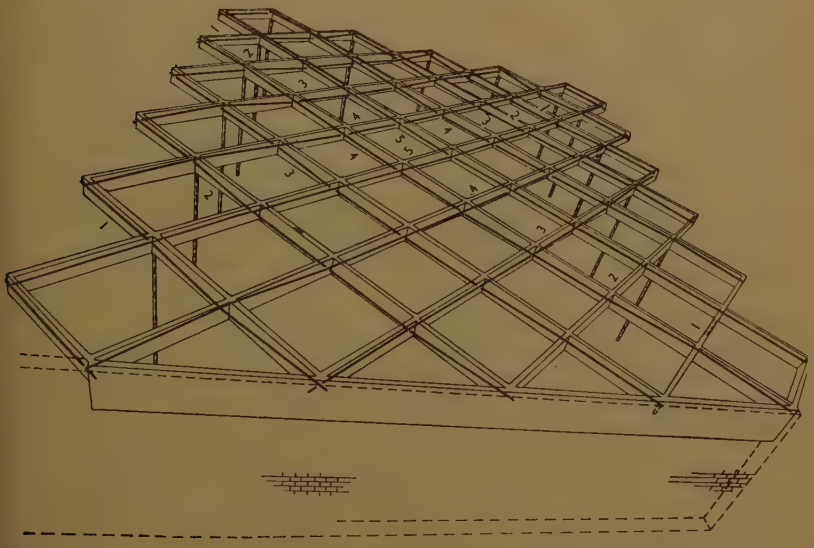
At the commencement of the job the contractor had had no knowledge of the quantity of concrete to be poured. A 1-yard batch mixer was therefore installed in Belvedere Road, and was very successful. It was clear of all the buildings there. The concrete was distributed by 2-cubic-yard tipping lorries. It would have been almost impossible to use small mixers, because the installation of drains and other services left such a restricted space round the buildings. The next most-used plant on the

site consisted of seven 4-hammer compressors, because so much of the material which had had to be excavated had required breaking up.

He would conclude by saying that if the contractor had to repeat the job he did not think that they would alter the organization which they had had on the site.

Mr R. S. Jenkins observed that the Authors had described the rather unusual situation in which the officially appointed engineers had found that some architects wanted to bring in other engineers. Mr Jenkins was a partner in one of the firms referred to as " private " engineers. That the arrangement had worked harmoniously had been mainly due to the

Fig. 17



Pre-stressed Roof Structure of Fairway Restaurant

very nice way in which it had been looked on by the late Sir Ralph Freeman and his son, who was one of the Authors. Indeed, it had been that attitude which had enabled his firm to accept the design work in the first instance.

He agreed with the Authors that fairly full descriptions of the buildings had appeared in the technical press, but he would like to say a little about one structure, not because of any intrinsic interest which it possessed, but because the opportunity would be taken to carry out some load tests on it. It so happened that his firm had designed two structures in pre-stressed concrete, which was a relatively new material, and it was felt that full-scale tests, to justify various bases of design, should not be neglected when the opportunity occurred.

One of the buildings concerned was the Fairway restaurant, to which

reference was made on p. 364. Each member between the junctions was pre-cast, and *Fig. 17* showed the post-tensioned cables in position. Those cables ran in holes through the elements and presented the effect of being woven together. *Fig. 17* showed which passed above the other, but it was difficult to see this on such a small scale.

The structure had been designed for ordinary roof loadings, but when the question of testing had arisen it became evident that it would be far too elaborate to load every junction, and it had been necessary to try to

Fig. 18

TEST-LOADING OF ROOF STRUCTURE

NOTE : The arrows indicate the position of the test loads. The direction will be perpendicular to the grid.

limit the test loadings to not more than six positions. That had been partly due to the desire to apply the loads by hydraulic jacks, so that they could be released and re-applied as frequently as required. Several arrangements of jacks had been investigated, and the one which had been adopted was shown in *Fig. 18*. It might be appreciated that, even taking into account two axes of symmetry, the structure had 10 degrees of static indeterminacy both with the original loads and the pre-stressing and test loads, and, though designed by ordinary methods, considerable refinement had been used to keep the amount of work within reasonable limits.

The main object of the test would be to see whether the ordinary methods of design using the principle of superposition were legitimate. Actually the calculated upward deflexion when the pre-stressing was done was confirmed. It had been calculated that, theoretically, under the test load and under its own weight, cracks should develop in the positions shown by the little wavy lines. It was not difficult to see in *Fig. 18* that a mechanism was developing, and there might therefore be an ultimate-load method of design.

Mr Jenkins then displayed a slide showing the calculated stresses at a point when tension was starting to develop, and said it could be seen that even though the test load was not distributed the same way as the design load—and pre-stressed concrete was specially sensitive to that sort of thing—the design was rational and tension was starting to develop in almost every beam simultaneously. The compressive stresses were all less than 2,000 lb. per square inch.

The bodies interested in that test were the Ministry of Works, the Building Research Station, the London County Council, and the Cement and Concrete Association. He had been informed that the other pre-stressed structure, the footbridge from the Waterloo gate to the Festival Hall, was scheduled for demolition, and his firm had been asked to investigate the question of testing that as well. No material relating to the second test was yet available.

Mr F. J. Samuely said that he was one of the " private " engineers who had worked at the Festival site, where he had designed the structures for the Power and Production building, the Transport building, and the Skylon. He had at first feared that the extraordinary situation in which there were two consulting engineers working on the same set of buildings might result in friction, but actually Mr Freeman's tact had been largely responsible for ensuring that none had developed.

Mr Samuely remarked that architects usually learned a certain amount about structures—how much depended more upon the architects themselves than upon anybody else—because every one of the recognized schools had a course on engineering. He was afraid, however, that engineers did not learn much about architecture and, whilst almost every architect at least knew what an engineer had to do, there were certainly a great many engineers who had not the slightest idea of what an architect was doing. If some engineers thought that architects spent their lives drawing elevations, he felt sure that they were wrong, because he had seen many other drawings which were obviously necessary.

In the case of the South Bank buildings the collaboration had been of extreme importance, partly because many of the architects had based their architecture on the structure, and partly because it had obviously been their wish to have in the Exhibition some buildings with a particularly good aesthetic appearance. He thought that in the short time available as much as possible had been done. One great difficulty had arisen from the fact

that, in April 1949, the architects and engineers had been nominated—at the same time as the theme conveners—and, whilst the buildings were supposed to go up 9 or 10 months later, nobody knew at that time what was to be displayed in those buildings, and so constant alterations had had to be made.

For the Power and Production building, the architect had tried his best for a long time to use temporary material, namely, tarpaulin, but it had been found that, in the circumstances, tarpaulin was much more expensive than orthodox construction, and the attempt had had to be abandoned, mainly on account of the cost. That consideration, he thought, affected all temporary constructions ; they were in all circumstances more expensive, and therefore caution should be exercised before suggesting temporary work.

On the question of general publicity, he agreed with Mr Lobb that the structure was not all-important, and that it was only a servant ; the building was the real concern. He could not agree with Mr Lobb, however, that at the South Bank the structure had obtained overriding publicity. In fact, so far as Mr Samuely knew, there had not been one daily paper which had ever mentioned the fact that the Dome structure, for example, had been designed by an engineer. It had certainly not been the fault of the architects that the engineers had received no publicity. Those architects with whom Mr Samuely had had to deal had done everything in their power to give publicity to the engineer, but there had been something somewhere which had prevented the names of the engineers getting into the daily press, or even anything being said about there being some engineering to be done on the South Bank. So far as he knew a special attempt to do something to remedy that state of affairs had been frustrated.

Mr H. J. B. Harding called special attention to the last paragraph under the heading of " Lessons " on p. 368, in which it was said that " At negligible extra expense, the architects made greatly effective use of colours on ordinary materials such as steel, asbestos, and concrete, so often left drab in industrial buildings." Engineers might well study that and remember that there were other colours besides Payne's grey and bitumastic. Those who had been fortunate enough to see the inside of the hot-metal house at Scunthorpe (Sir Frederick Gibberd's design) would agree that it gave one a feeling of uplift which was quite extraordinary.

He hoped that the South Bank site would not be allowed to become a " depressed area," full of Government and Local Government offices. One newspaper had suggested that if Government offices had shops in the bottom floor it would relieve their dreariness.

So far as publicity for engineers was concerned, if *The Times* had an engineering correspondent as well as an architectural correspondent many of the troubles of engineers in that respect would disappear.

One or two engineering foundation troubles had been overcome which

were not mentioned in the Paper. One was in connexion with the escalator at Waterloo station, which had been constructed through 18 feet of water in the gravel under a hood of chemically consolidated sand and gravel in free air. That had required courage on the part of all concerned. At Charing Cross the water had been lowered for the new escalators by means of six wells 20 inches in diameter, with a submersible pump in each. That was the third time that the water had been lowered at Charing Cross for escalators. It had first been done before the 1914–18 war, when Mr Dalrymple Hay had used sumps. The nearby landlords had insisted that no water should be removed from the ground, and so Mr Hay had sunk sumps and pumped the water back into the ground further away, so claiming that he had removed no water from the ground.

Mr D. H. Little expressed particular interest in the speed with which the work had been carried out and the method by which it had been done. It had been stated, he observed, that something like £7,500,000 had been spent in 2 years. In that respect it was very similar to some of the big oil refineries which were now being built, where about £40,000,000 was being spent in five years. It would be of interest to know how that was done and what had to be done to achieve it, who paid for it, and how much it cost to do it in that way.

Taking the average run of jobs costing from £250,000 to £500,000, 6 months might be occupied in preparing drawings for them, and a similar time on the quantities and tendering. When the job began, the first argument with the contractor might lead to a stoppage of the work, because the contractor had had to pay overtime to the men and had not allowed for it. A £500,000 job done in the ordinary way would thus take a year or 18 months to prepare and 2 or 3 years to carry out, but those jobs were done on a competitive basis, which was presumably also an economical basis, because it was the way in which most work was done. Those other huge jobs, however, could be done at a most remarkable rate, and it would be interesting to know what the Authors thought that it cost in extra money, and whether the additional cost was 10 per cent, 50 per cent, or, as he imagined, 100 per cent more than the orthodox ways of carrying out the work.

There were, of course, intangible factors to be considered. The South Bank Exhibition had to be finished by a certain time, and an oil refinery had hidden assets behind it when it got to work. He would like to know, however, what the Authors thought was the extra cost of doing the work in that way, and whether it was or was not economically sound.

Sir Hugh Casson, in reply, said that Mr Fuller had asked whether the individual architects had not been given too much freedom. The answer perhaps was, in principle, No ; in detail, Sometimes. When they started, each architect had been left a good deal to himself, but naturally as time went on he (Sir Hugh) and his colleagues, perhaps gaining in self-confidence, had become stricter in their requirements. After all, many of the architects

working on the site had had more experience than himself, and it was perhaps diffidence, as well as the unusual relationship between architect and architect, which had resulted in the control being at times looser than it should have been.

He had nothing to add to the answers given by other speakers on the question of temporary buildings, but he wished to underline Mr Lobb's remark on distinguished visitors. They were undoubtedly an assistance to morale despite the working hours often lost.

The canteen referred to by Mr Mulholland had been a real difficulty. It had taken up a great deal of room, it had required services, and had always been in the way. But the workmen had to have somewhere to eat and the canteen had therefore had to remain on the site until a few days before the opening.

Mr Samuely had reproved the theme conveners gently as having been guilty of causing some delay. It was true that it had been difficult to extract information from them, as indeed from anybody, but it should be remembered that their job had been very difficult, including not only the persuasion of industrialists to lend exhibits ranging in size and complexity from a champion cow to a microscope, but also the organization of cartage, insurance, cataloguing, and placing. There had been many thousands of exhibits and industrialists had been anxious to show the very latest product. Inevitably there had been delays and last-minute changes, for which the theme conveners could not be unduly blamed.

With regard to publicity, also referred to by Mr Samuely, Sir Hugh agreed that the engineers did not seem to get anything like their fair share. That was no fault of the Festival Office. Every publicity document sent out from the Festival Office had included the name of the engineer together with that of the architect. But very often the name of the engineer had been omitted when the document appeared in the Press. It seemed that somewhere in the newspaper world there existed a suspicion that the engineer was a technician, whose creative contribution was only of a minor character, and Sir Hugh thought that the Institution might well try to see whether that attitude of mind in the Press could be revised, so that the engineer always received proper credit for the work that he did.

Other speakers had referred to the question of collaboration between engineer and architect, between engineer and engineer, and between architect and architect. Sir Hugh said that, so far as he was concerned, that had proved to be one of the most instructive and pleasant features of the South Bank project. The Exhibition had been an unusual experiment in professional co-operation. Architects had been commissioned by other architects to work for them, and the same arrangement had been in force with the engineers. It might have been difficult as well as unusual, but in fact it had not proved to be so. He thought that the Festival Office had been extremely fortunate throughout the whole job in the team of engineers with whom they and their architectural colleagues had worked.

Of personal interest to him had been the way in which the South Bank Exhibition had removed his distrust of engineers for seeming to make things far stronger than was necessary. He had discovered that such caution—or perhaps it would be politer to say foresight—had its uses. Two examples of that he remembered particularly clearly. One was the cantilevered radar apparatus, carrying the scanner at its top; the other was the suspended view-points above the river, in front of the Festival Hall. The first feature had been a very late comer to the Exhibition and there had been great difficulty in finding a site for it. Its height had been fixed and it had had to be within a certain distance of the river bank. Many of the architects approached had viewed its arrival with suspicion. Eventually it had been suggested that it might go on the already completed roof of the Transport Pavilion, and there it had been placed, adding unpredicted stresses to a structure which, however, had not seemed to require any amendments to take it. [He had learned since the discussion took place that the end roof girder of that building had, for simplicity, been made the same size as the others, though carrying only half the roof load; quite fortuitously, therefore, the end girder had had a reserve of strength sufficient to carry the radar mast.] As to the second example, when he had first seen the assembly of masts, turnbuckles, hawsers, and counterweights going up in front of the Festival Hall, it had seemed to him that those were unnecessarily strong. But some months later, when the Smith brothers had set out for their Atlantic crossing from the downstream pier, the little viewing platforms had been so crowded with spectators—far more, it had seemed, than any calculated load—that he had been thankful for the foresight of the engineers concerned.

Much of the building work in the Exhibition had been experimental in form, but he had never encountered the word "impossible" from any of the engineers, and both architects and engineers had throughout worked very happily together upon a project which he was sure all those concerned could look back upon with pleasure as well as with pride.

Mr Ralph Freeman, who also replied, thanked Mr Fuller for pointing out the error in the Paper with regard to the water level; the Authors would add a footnote drawing attention to the correct figure as given by Mr Fuller. Mr Freeman had quoted the figure from memory, without looking up any drawing, and that explained the error. Mr Fuller had explained that the filling behind the river wall had been consolidated with bulldozers, but that was perhaps a misunderstanding of what the Authors had been trying to convey. They had mentioned the filling behind the river wall, but later on, when talking about consolidation, they had been referring to the consolidation of the ground under their foundations with rollers which they had ordered to work there, whether it happened to be behind the river wall or not.

Mr Fuller had asked why the Mining building, the so-called "tetrahedron," had not been made of steel. It had been wished to make an early

start with a few buildings, and it had been necessary to consider not only the time which it would have taken to get the steel but also the time involved in designing the building in steel. It had been considered that, by using concrete, the work could be started, and therefore finished, more quickly. The use of timber had been considered, and in Mr Freeman's view that would have been the ideal material for that structure, but the use of so much timber had not been sanctioned.

Other speakers had answered Mr Fuller's point about the not sufficiently temporary nature of the buildings, particularly in the upstream area. Mr Freeman could only say that temporary construction had been adopted wherever possible, taking into account the winter which the buildings had to withstand and the various snow loads, superimposed loads, and wind loads which they had had to be designed to carry, and also having regard to the cost. It had been found, as other speakers had said, that in general the more traditional types of cladding were far cheaper than such materials as canvas.

Mr Fuller had referred to Table 2 and had pointed out, quite rightly, that all the works under the ownership of the L.C.C. had been tendered for in competition in the normal way. The Authors had not intended to suggest anything to the contrary. The Paper was concerned with the South Bank Exhibition buildings, and the Authors had tried to make it clear that they were referring to the Exhibition buildings and did not include the Festival Hall and many other works shown in Table 2. That Table was given to indicate the number of different jobs being done by different people at the same time on the same site, and, though they were all different people, they had had to use the same ground. Mr Freeman would like to thank Mr Fuller for giving a list of the very good work done by the South Bank Co-ordinating Committee. That Committee, and more particularly the *ad hoc* sub-committees which had sat from time to time in Mr Fuller's office, had proved very valuable in sorting out the endless problems which had arisen between the various people who had been doing the jobs listed in Table 2.

Mr Freeman would like to thank Mr Lobb for his remarks, and also Mr Mulholland. He agreed with what they had said, but would like to qualify Mr Mulholland's comment at the beginning of his remarks by saying that when Mr Mulholland had come to the site with only a foreman and a surveyor and no drawings, he had known before he set out that he had no drawings; he had been told, but had come in spite of that.

What Mr Jenkins had said about the Fairway Café roof was very interesting, and the tests which were going to be carried out on that structure should be valuable. Mr Freeman had always been very impressed by that design, and he hoped that the tests would help to provide new knowledge and to improve the technique of pre-stressed concrete construction.

Mr Little had commented on the great cost of work done in so short

a time, and had pointed out that with a smaller job of, say, £500,000, it usually took longer to carry out the design and construction and obtain the tenders. Mr Freeman agreed, and in mentioning the figure of £7,500,000 had done his best to make it clear that that was not the cost of the Exhibition buildings (which alone were the subject of the Paper) but of all the works on the site added together. It had not been one job, but a whole series of jobs which had been done by separate organizations on the same site, and no one architect, engineer, or owner had been concerned with the spending of £7,500,000. Being spread out in that way, the design work and so on had been done by a great many people, far more than could normally be organized to work on one job.

Mr Little had asked whether the Authors could make an estimate of the extra cost of telescoping the usual arrangements for design, tendering, and construction. Mr Freeman could not give that information, never having made any assessment. There would be a difference, he thought, but in his view it would not be very great and certainly not anything like the 100 per cent imagined by Mr Little. In the Exhibition building work, about 34 per cent in value of the contract work done had been in sub-contracts, for which competitive tenders had been obtained in most cases, so that they had not just been going ahead without any relation at all to normal procedure.

Mr R. T. James, who also replied, referred to the question of architects and engineers working together and observed that too much emphasis was placed on engineers being concerned only with the structure of a building. The " shape " of an architect's brain was different from the shape of the brain of an engineer. When the architect started his sketch designs, the engineer came in primarily on the matter of the frame and advised, say, where stanchions should be placed ; but, if he was a good and experienced engineer, and not narrowly structural, he would also help the architect in many other ways needing basic engineering knowledge to develop the design and to bring the building into being. That was the way things had worked in the South Bank Exhibition. The engineering referred to in the Paper was not narrowly structural but covered every aspect, including all the services. It was that engineering aspect and attitude which the Authors had in mind when they talked of collaboration between architects and engineers, and that applied to all building.

The closing date for receipt of Correspondence on this Paper has passed and no further contributions (other than those already received at the Institution) can be accepted.—Sec. I.C.E.

SUPPLEMENTARY MEETING

28 February, 1952

ALLAN STEPHEN QUARTERMAINE, C.B.E., M.C., B.Sc.(Eng.),
President, in the Chair

A discussion on the subject of the " Relative Economics of Pre-stressed Concrete compared with other Forms of Construction " was initiated by the following six Introductory Notes and, on the motion of the President, the thanks of the Institution were accorded to the Introducers.

"Relative Economics of Pre-stressed Concrete compared with other Forms of Construction—Aluminium ; Reinforced Concrete ; Steel ; and Timber"

" A General Review "

by

John Ratter, C.B.E., B.Sc., M.I.C.E.

ENGINEERS in this country are faced to-day with shortages of steel and other construction materials, and of labour, for which there is no precedent in days of peace.

Impoverishment caused by war is being followed by an urgent demand for new construction and manufacture, at home and abroad, to repair the ravages of the war itself, to improve standards of living, and to re-arm with modern weapons.

In this crowded country, perhaps more than in any other, economy in the use of material is vital to our existence.

A great responsibility is thus placed on the engineer to use his ingenuity to economize in material and labour, and so to play his full part in the economic recovery of his country.

The present discussion touches, therefore, on a subject foremost in the minds of us all, and our thoughts naturally turn to this exotic new medium, pre-stressed concrete, with all its early promise of economy in material and maintenance.

The purpose of these notes is to introduce a discussion on the relative economic merit of pre-stressed concrete compared with other media, and

so it is desirable to consider what factors must be studied by the engineer in his quest for economy in the construction of his works.

The following are important among them under present-day conditions :—

(1) First cost.
(2) Cost of maintenance.
(3) Long life of the structure, with maximum resistance to corrosion or other forms of decay.
(4) Ease and speed of erection.
(5) Availability of material when it is wanted.
(6) Security against fire risk or other emergency such as war damage.
(7) Aesthetic features.

The best design under each heading can never be achieved in one structure.

Usually the answer is a compromise, often dictated by expediency.

The engineer must make the best of the money and material that is placed at his disposal. To do the perfect job, there is rarely enough of either.

It is perhaps useful to consider each factor separately and to note what pre-stressed concrete has to offer in comparison with some of its rivals in each case.

The first cost.—The first cost of a pre-stressed concrete structure should be cheaper than a similar structure built in reinforced concrete or steel.

In straightforward work such as simple bridgework, this is almost an invariable rule. In more complicated structures, however, the reverse is often found.

Whilst less material is required, manufacturing and labour costs are often high owing to the high quality of workmanship that satisfactory construction demands, and to the comparative lack of experience in the technique of design and erection.

This situation may well change, as experience and confidence grow.

Cost of maintenance and life of structure.—Very little reliable experience is available upon which to base an opinion on the claims of pre-stressed concrete to produce maximum economy on this score. Only time will tell. In theory, pre-stressed concrete possesses many advantages over other media. The concrete will not crack, of necessity it is of the best quality, and cables are usually well protected.

Much has been said about the possibility of failure as a result of fatigue, unforeseen changes leading to loss of pre-stress, and corrosion of cables at dry joints, and there is still much room for basic research on these and other like subjects.

But there appears to be no solid reason for fear.

No one has such fears of properly built reinforced-concrete structures,

and though cables and wires are much more vulnerable should corrosion attack them, they are better protected against it than are reinforcement bars.

Ease of erection.—In this field, steel still has the advantage, particularly in bridgework where rapid erection is required with minimum hindrance to traffic. It should be mentioned, however, that pre-cast deck units and slab units, in both reinforced and pre-stressed concrete, have been developed for railway work, possessing all the virtues of fabricated steel in convenience of erection.

In larger structures and in much building work, with the attendant need for staging and shuttering, concrete is at a disadvantage.

Availability of material.—At present, steel and aluminium must be saved. Timber is only slightly less scarce. Concrete is in good supply. The inference is obvious. It is devoutly to be hoped that the steel allocation schemes will work so that the engineer receives his ration in full and on the promised date, and that reinforcement bars and high-tensile wire will be in supply properly proportionate to our need.

Security against fire risk and other damage.—Many of us have had experience of the extraordinary tenacity of reinforced concrete and of steel against bomb damage.

Pre-stressed structures, with their all-important wires and cables, have not the advantage of such security.

Little is known of the fire risk, but research on this subject is proceeding in this and other countries.

Aesthetic features.—Pre-stressed concrete can be shaped into attractive graceful forms. Beams can be slender and shallow, and the development of the medium in the construction of new building features is in its earliest stages.

It can give homogeneity to a structure in a way that steel cannot. Steel, however gracefully fashioned, must in most civil engineering structures remain a skeleton. Aluminium gives promise of quite new ideas in building construction, but its use in such work may still be described as a novelty.

In a preliminary note such as this, it is not intended, nor is it desirable, to attempt to reach a conclusion.

It is perhaps enough to say that the most potent influence governing the design of our structures to-day, and the speed with which we build them, is not our arts, or our sciences, but international economics—the key-words of the era.

" Aluminium Construction "

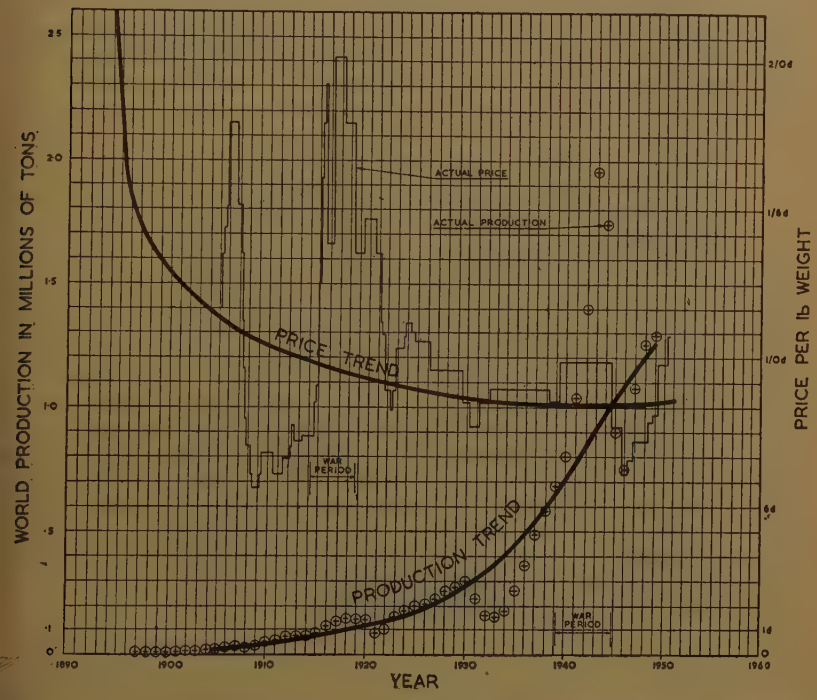
by

Douglas Victor Pike, A.M.I.C.E.

In order to appreciate fully the economics of aluminium alloys in structures, it is advisable, before considering their technical characteristics, to note developments in their production and price.

Fig. 1 shows the remarkable decrease in cost with expansion of production during the past 50 years. It is reasonable to forecast that,

Fig. 1



Relationship between Expansion of Production of Aluminium and Decrease of Cost

accompanying the expected great future increase in production, there will be some further reduction in price relative to other materials.

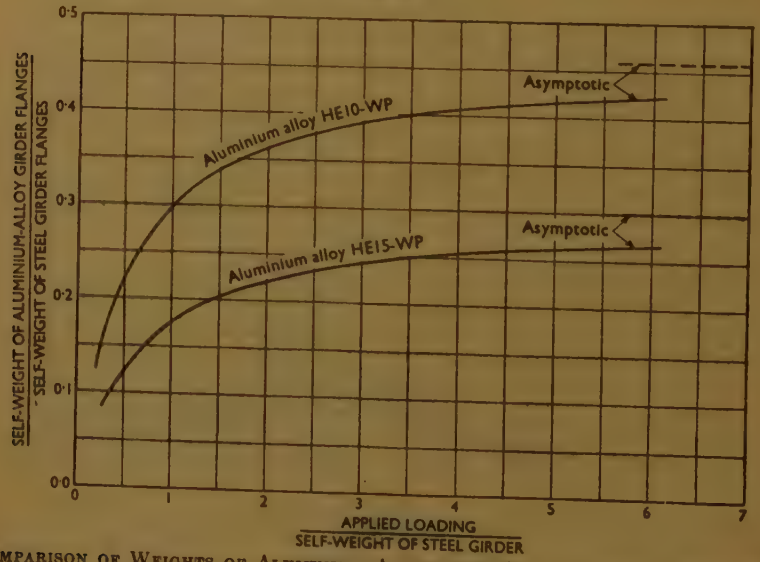
Improvements in methods of producing and fabricating the alloys are also continually taking place. For example, the cost of aluminium alloy sections today is only slightly greater than in 1939, whilst all other structural materials have at least doubled in price.

The relative fall in price of aluminium alloys and the growing appreciation of their technical properties has, year by year, widened their field of structural application. Even so, it cannot be suggested that this field includes structures other than those associated with conditions in which the special properties of aluminium alloys may be used to great advantage.

The most advantageous property of aluminium alloys is their high strength/weight ratio. Their specific gravity is about one-third that of mild steel. With working stresses of $6\frac{1}{2}$, 7, and 10 tons per square inch respectively for the three alloys most used for structures—HE 10–WP, HE 15–W, and HE 15–WP—and 9 tons per square inch for mild steel, the strength/weight ratios of these three alloys and mild steel under tensile forces are in the proportion of $6\frac{1}{2} : 7 : 10 : 3$.

If the applied loading on a girder is high compared with its self-weight the forces in the members are only slightly less in aluminium alloy than in mild steel. Thus with HE 10–WP, HE 15–W, and HE 15–WP, using the foregoing proportions, the respective self-weights are approximately 46 per cent, 43 per cent, and 30 per cent of the weight of a mild-steel girder on a tension basis only.

Fig. 2

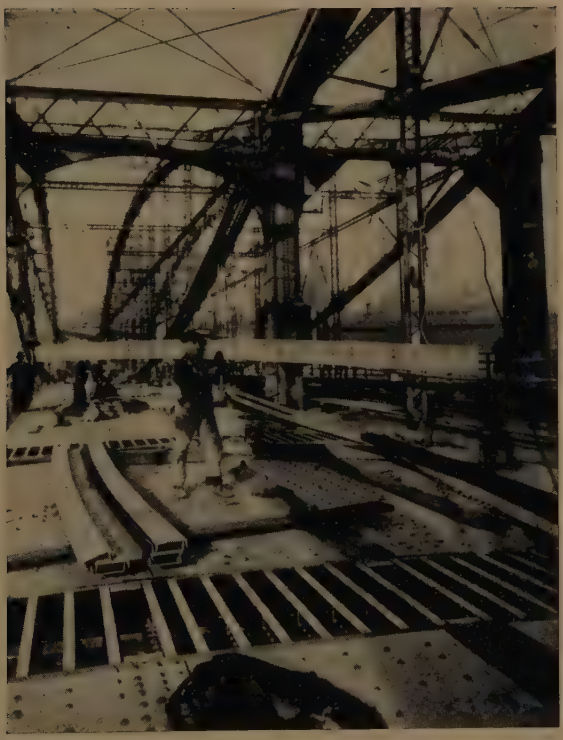


Comparison of Weights of Aluminium Alloy with Steel Tension Flanges of Girders

But, if the ratio of applied loading to self-weight is small, the weight saving is much greater, as suggested by *Fig. 2*. These curves are drawn from the relationship :—

$$f_A\left(\frac{w + W_S}{W_S}\right) = f_S\left(\frac{w + W_A}{3W_A}\right)$$

Fig. 3



Reflooring the Pittsburgh Bridge in 1933

Fig. 6

[*By Courtesy of Aluminium Company of America*]

100-FOOT RAILWAY SPAN AT MASSENA, NEW YORK (1946). MATERIAL: H 10 WP. RIVETS: H 13T. PAINTED

Fig. 7

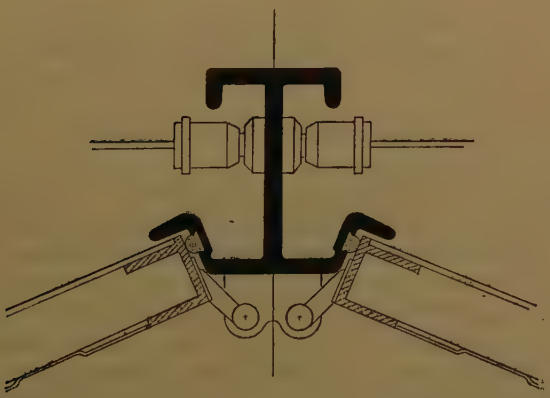
150-FOOT CRANE JIB FOR 10-TON DERRICK (1951). MATERIAL: H 10 WP. STEEL RIVETS. PAINTED

where w denotes the applied load; W_S the weight of a steel girder; W_A the weight of an alternative aluminium alloy girder; and f_S and f_A the working stresses for steel and aluminium alloys respectively. Thus, for instance, the total loading on crane girders carrying light external loads is much less if they are aluminium alloy girders than if they are mild-steel girders, and the aluminium self-weight is accordingly reduced.

Whilst these weight-comparisons require adjustment, unfavourable to aluminium alloys, to allow for their higher elasticity ($E = 10 \times 10^6$ lb. per square inch), this may be minimized by the use of aluminium special sections designed to use the material to greater advantage. Almost any section within a 15-inch-diameter circle can be extruded, and, since the cost of a special die is low, the use of special sections may be economical even for small quantities.

The re-flooring (in 1933) of the Pittsburgh Bridge (see *Fig. 3*), exemplifies the principle of using aluminium to re-model existing structures. In this case, by replacing the old steel-supported floor by an aluminium alloy system, the bridge became suitable for modern traffic. Proposals to add a roadway to the existing Forth Bridge by using aluminium alloys provide a more recent appreciation of this principle.

Fig. 4



Special Section used for the Sliding Doors of the Brabazon Assembly Hall at Filton

Special sections may be used for other reasons than weight saving: for instance, the section used for the Brabazon Assembly Hall sliding doors (see *Fig. 4*) combines structural and mechanical features otherwise unattainable.

The low weight of aluminium is also beneficial where movement of the structure in any manner is an important item. Military bridges are an obvious example, as are certain types of buildings designed for easy dismantling and re-assembly. Transportation over long distances, involving

frequent changes of vehicle and difficult terrain, are greatly simplified. Erection costs also may become comparatively light and completion of the structure effected more quickly.

The high corrosion resistance of aluminium alloys is another important economic factor. In many cases no surface protection of any kind is necessary—indeed, unpainted aluminium alloy is often preferred aesthetically—and, in general, maintenance is low. Care is necessary, however, to prevent electrolytic corrosion when aluminium alloys are connected to certain other materials including steel.

Although some examples have been given where a particular property of aluminium alloys has been predominantly influential to their choice, other properties are beneficial, to some degree, in all cases. Usually where economics are favourable, it is the result of the summation of specific properties of the alloys, as in the Dome of Discovery, the Clunie Bridge, and the Bristol Prefabricated Schools.

Full realization of the advantages of aluminium alloys, including ease of fabrication and erection, comes only from experience. It is fair to say that engineers and fabricators have often expressed an appreciable adjustment of their ideas in this respect after carrying out works involving these materials.

" Reinforced Concrete Construction "

by

Frederick Sidney Snow, M.I.C.E.

Reinforced concrete was introduced for general use at the beginning of the present century and thus has been tried and proved over this period.

No other material has brought about such revolutionary changes in construction and no other form of building is a serious competitor. It can and does to a very large extent supersede timber, and the aluminium alloys are by no means formidable rivals, if price, maintenance costs, and speed of erection are qualifying factors. Indeed there is no doubt that such structures as the Dome of Discovery could have been more economically constructed in reinforced concrete had not other considerations prevailed; even so the Dome was largely supported on reinforced-concrete piers, etc., and the same principle applies to practically every other form of construction.

Until recently the most serious rival to reinforced concrete—particularly in structural frameworks—was structural steel, but even prior to the present steel shortage, reinforced concrete was cheaper than structural steel in areas where the L.C.C. regulations apply, that is to say, where structural steelwork has to be encased.

Today, the advantage of first cost and maintenance is heavily in favour

of reinforced concrete. Criticism has been made in the past on the subject of speed of construction but it can definitely be asserted that where the work is carried out by a competent contractor the time required for the construction of reinforced concrete works is no greater than that for steel.

Reinforced concrete by its very nature gives great flexibility in design ; it can be fashioned into pleasing shapes and, with the surface treatments now developed and applied, cannot offend even the most aesthetic tastes, as instanced by the many examples of buildings erected at the South Bank Exhibition (Festival of Britain, 1951).

Reinforced concrete is infinitely superior, from a fire-resisting point of view, to any other material referred to in this discussion, and it was successfully proved during the war years that the continuous fixity of connexions was unsurpassable in its resistance to aerial attacks, and repairs to bomb-damaged structures were more easily and cheaply dealt with.

Commenting on present-day shortages, production of round-rod steel for use in reinforced concrete had reached close upon 200,000 tons in 1938 ; in 1939 it rose to about 330,000 tons but in 1946 it fell to 140,000 tons and by 1950 it had risen to 250,000 tons.

Towards the end of 1950, home demand increased and there has been a considerable shortage of all classes of steel for building construction, and contractors have experienced great difficulty in securing the supplies necessary to complete their contracts.

The scarcity of steel, which is largely influenced by the shortage of coal, affects all consuming industries and it is universally accepted that reinforced-concrete structures absorb only about one-third to one-half of the tonnage of steel required in comparable structural steel frames. It is quite apparent that, with the continued shortage of coal and other materials, Great Britain will—like most Continental countries—become more and more " reinforced-concrete-minded."

In recent discussion with the Reinforced Concrete Association the following Table was quoted which gives the ratio of the tonnage of round-bar steel used in reinforced-concrete buildings as compared with that used in similar steel structures :—

Factory buildings	1 — 2¼
Warehouses	1 — 2¾
Flats, Offices, etc.	1 — 2

It is as well to point out other fields where reinforced concrete has played its part. For instance, in the first World War, a considerable number of reinforced-concrete barges and ships were constructed, and there are records of more than 15 years' service for reinforced-concrete steam tugs, with very low maintenance costs.

There is also the Mulberry Harbour scheme which would have been impossible to erect in material other than reinforced concrete.

Pre-stressed concrete cannot be considered as a dissimilar material to reinforced concrete as it is only a natural development in design, but it is to be emphasized that no large-scale tests have yet been made for the effects of fire or possible corrosion and a number of years will have to elapse before any great faith can be placed in this form of construction.

Nevertheless, where pre-cast units are concerned, it is certain that pre-stressed concrete, if judiciously used with a reinforced-concrete frame, will gain favour by its saving in steel and cement and will detract still further from the present advantages of such materials as timber, aluminium, or steel.

At the present time the cost of pre-stressed reinforced concrete exceeds that of normal reinforced concrete, owing to the amount of labour involved.

There is food for thought in the fact that it takes approximately 2·1 tons of coal to make 1 ton of structural steel, whereas the manufacture of a ton of cement requires the consumption of not more than 0·5 ton of coal.

" Steel Construction "

by

Hubert Shirley Smith, O.B.E., B.Sc.(Eng.), M.I.C.E.

Advantages of Structural Steelwork

Production.—Mild steel and high-tensile structural steel are produced with complete reliability and conform to guaranteed limits of ultimate strength, yield point, etc. Their strength is not dependent on site supervision as is that of pre-stressed-concrete structures built in situ.

Erection.—A steel structure can be erected far more quickly than pre-stressed concrete. It gets a flying start because the steelwork can be fabricated complete in the shops whilst the foundations are being prepared at site. Steel bridges are more adaptable to a variety of methods of erection, such as cantilevering, and can be built with far less staging than would be required for a concrete bridge built in situ.

Appearance.—By means of flame-cutting and welding, structures such as steel portal frames can be manufactured easily and cheaply to any desired curve or degree of slenderness; thus, in addition to good appearance, economy in weight and cost is also achieved.

Alterations.—By similar methods an existing steel building can be modified or extended more quickly and with much less expense than a pre-stressed-concrete building.

Maintenance.—The latest methods of cleaning and protection by means of grit-blasting, metal-spraying, and painting bid fair, at the small cost of re-painting every 7 to 10 years, to prolong the life of steelwork almost

indefinitely. Moreover, stainless steel of structural quality can now be made and its commercial production may not be many years ahead.

Tubular steelwork.—Tubes, of course, are the most efficient section of strut known; the advent of welding and other processes is leading, particularly on the Continent, to a great expansion of tubular construction. Tubes can now be obtained of rectangular section in mild or high-tensile steel, ranging from small sizes suitable for handrailing to square sections of 12-inch side more than 1 inch thick; the big sections are rolled hot in Pilger cogging mills and have no seams. Tubes of rectangular section are, of course, admirably suited for columns or chords of girders. Web members can be cut to shape at the ends and the connexions welded. Notable buildings in which tubular construction has been used include Exhibition Halls in Brussels, Liége, Antwerp, and Cologne and the Dome of Discovery at the Festival of Britain.

Exports.—Iron and steel are the traditional materials of Great Britain, on which its eminence has largely been founded. For years past, Britain, as the centre of the Empire, has exported great quantities of fabricated structural steelwork for bridges, buildings, and other requirements. It would be a sad day indeed if this country ever had to attempt to replace these valuable exports of steel with pre-stressed concrete.

Pre-stressed Concrete

Pre-stressed concrete has come to the fore in a world of grave shortages, and in such conditions it has its best chance of expansion. The idea was exploited by Considère in the first years of the twentieth century—very shortly after structural steel came to be universally accepted. It was only slowly developed, however, until after the second World War when Eugène Freyssinet, its principal pioneer, used the system in the reconstruction of bridges in Tunisia, where there was hardly any timber for shuttering or steel for reinforcement.

The high stress in the wire.—In modern pre-stressed concrete, cold-drawn wire of 0·196 inch diameter and having an ultimate strength of 100 tons per square inch is stressed up to about 70 and employed at a working stress of 65 tons per square inch. This is double the working stress at which the same kind of wire is used in long-span suspension bridges. The wire is either grouted in situ after tensioning or galvanized wire may be used inside tubes which are subsequently sealed. The behaviour with age and the length of life of cold-drawn wires employed in a structure in which the stress is permanently maintained at about 65 tons per square inch are not known and give rise to grave doubts in the minds of some engineers.

Application of the method

(*a*) *Buildings.*—In building construction, pre-stressed concrete appears to have little chance of competing economically with

structural steel. It can give no economy over reinforced concrete in columns and any saving it might produce in the beams is lost in the difficulty of achieving continuity.

(*b*) *Bridges.*—In spans of 50 feet or less, where reinforced concrete can compete with steel, and the beams can be pre-cast in the shops, pre-stressed concrete should be in a favourable position. For spans ranging from 50 to 200 or 250 feet its advantages become progressively less. For spans greater than 250 feet, where the staging begins to be formidable, structural steel is the master.

Risk of corrosion.—The claim that reinforced concrete would produce maintenance-free structures has (with a few notable exceptions) failed sadly of fulfilment; if repairs are required they are liable, even if practicable at all, to be very costly. It is essential that the concrete used in pre-stressed work should be literally flawless, solid, compact, and without trace of honeycomb, for if frost gets into any imperfections in the concrete it will, in spite of the state of compression, cause cracking. There is no margin in the area of the highly stressed wires to allow for corrosion and unless they are completely protected their life will be short.

Effect of shock.—Experience in World War II showed that structural steel frameworks are well able to withstand the effects of blast. In a pre-stressed-concrete structure it may well be that the shock would snap the highly stressed wires like overtaut violin strings and so result in total failure.

Labour costs.—France, Switzerland, and Sweden are the traditional leaders in reinforced-concrete work, and in those countries skilled labour, trained in the shuttering and casting of thin slabs and the manipulation of the wires, is available and relatively cheap. In Britain, and to a greater extent in America, where labour is very expensive and concrete and steel less scarce, the increased labour costs must be offset against the saving in material.

" Timber Construction "

by

Phillip Oliver Reece, A.M.I.C.E.

In beams and slender struts and in components or parts the strength of which is governed by their elastic stability, variations in the dimensions of their cross-section have, in general, a greater effect on their strength than have equal variations in the mechanical properties of the material. From this it may be shown that if comparison is made between two materials of the same strength/weight ratio but of different densities, the

lower density material will be the more efficient for the purposes mentioned owing to the greater thicknesses afforded by the same weight of material.

In ties and stocky struts, variations in dimension are, in general, of equal importance to variations in mechanical properties, and in these cases the strength/weight ratio becomes a criterion of efficiency irrespective of variations in density.

These ideas can be generalized by employing the criterion of specific strength, here defined as the load sustained by a unit weight of structural material under a particular condition of loading; its usefulness as a criterion lies in the extent to which it can direct attention to the conditions of loading under which one particular material has a higher efficiency than another.

If P denotes a sustained load
W ,, the weight of the supporting member
g ,, the specific gravity of the material
p ,, a unit stress imposed by the sustained load
A ,, the cross-sectional area of the supporting member
Z ,, the modulus of section of the supporting member
and I ,, the moment of inertia of the section

then
$$S_g = \frac{P}{W} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where S_g is the specific strength of the material. For members of the same weight and length:

$$S_g \propto P \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

It follows that:

$$S_g \propto pA \text{ in tension, direct compression, and shear} \quad . \quad . \quad (3)$$

and:
$$S_g \propto pZ \text{ in flexure} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

In geometrically similar sections of materials of different densities it may be shown that:

$$A \propto \frac{1}{g} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

$$Z \propto \frac{1}{g^{1.5}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

and statements (3) and (4) may be rewritten thus:

$$S_g \propto \frac{p}{g} \text{ in tension, direct compression, and shear} \quad . \quad . \quad (7)$$

$$S_g \propto \frac{p}{g^{1.5}} \text{ in flexure} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

Of increasing importance to modern engineering is the thin-walled or slender component which fails at comparatively low stresses through

elastic instability induced by compression, bending, or torsion. A general case of this kind of failure is one in which P is a function of EI; equation (2) then becomes:

$$S_g \propto EI \quad \ldots\ldots\ldots \quad (9)$$

In the comparison of materials of different densities, it may be shown that:

$$I \propto \frac{1}{g^2} \quad \ldots\ldots\ldots \quad (10)$$

and (9) may therefore be written:

$$S_g \propto \frac{E}{g^2} \quad \ldots\ldots\ldots \quad (11)$$

In structures involving the problem of impact and suddenly applied oads, the ability of the material to absorb energy becomes of the first importance. This is a function of the modulus of resilience, the criterion for the amount of energy stored per unit weight of material being given by:

$$u \propto \frac{p^2}{Eg} \quad \ldots\ldots\ldots \quad (12)$$

Table 1 shows working stresses for Douglas fir and pre-stressed concrete. The values required for comparison are, however, those which are available to carry superimposed load after the dead load has been deducted. In the preparation of Table 2 it has been assumed that the dead load of timber construction is 20 per cent of the live load, and 50 per cent in the case of pre-stressed concrete. The strength-values of Table 2 are consequently five-sixths and two-thirds of those in Table 1 for Douglas fir and pre-stressed concrete respectively.

With the aid of equations (7), (8), (11), and (12) it is possible to make a quantitative comparison of the efficiencies of the two materials as shown in Tables 3 and 4. This analysis measures efficiency in terms of the load sustained by a unit weight of structural material. The criterion is valid when the saving of weight is important. It is fundamental to many kinds of structure but its more general importance emerges during times of scarcity of material.

In normal circumstances the criterion for the bulk of engineering structures will be one of cost rather than weight, and Tables 3 and 4 should be modified accordingly.

If S_g denotes the load sustained by 1 lb. of material, and d the cost of the fabricated material in pence, then:

$$\frac{S_g}{d} = \text{the specific strength per penny cost}$$

$$= S_d \quad \ldots\ldots\ldots\ldots\ldots \quad (13)$$

Equation (13) may be used to assess the economic suitability of a

material for a particular condition of loading. Generalization here is difficult owing to the wide variation of costs of the same material in different kinds of structure, but for the purposes of illustration the following costs have been assumed in the preparation of Tables 5 and 6:

Douglas fir . . . . . 10*d.* per lb.
Pre-stressed concrete . . . 2*d.* per lb.

TABLE 1.*—PHYSICAL PROPERTIES and PERMISSIBLE WORKING STRESSES

Material	Specific gravity	Modulus of Elasticity lb. per sq. in.	Working stresses: lb. per square inch			
			Bending	Tension	Compression	Shear
Douglas fir .	0·48	$1{\cdot}6 \times 10^6$	1,000	1,500	1,000	100
Pre-stressed concrete .	2·30	$5{\cdot}0 \times 10^6$	2,000	2,000	2,000	500

TABLE 2.—WORKING STRESSES AVAILABLE FOR LIVE LOADS

Material	Modulus of Elasticity lb. per sq. in.	Working stresses: lb. per square inch			
		Bending	Tension	Compression	Shear
Douglas fir .	$1{\cdot}33 \times 10^6$	833	1,250	833	83
Pre-stressed concrete .	$3{\cdot}33 \times 10^6$	1,333	1,333	1,333	333

TABLE 3.—SPECIFIC STRENGTH—STATIC LOADING

Material	Flexural rigidity $\frac{E}{g^2}$	Bending $\frac{p}{g^{1.5}}$	Tension $\frac{p}{g}$	Compression $\frac{p}{g}$	Shear $\frac{p}{g}$
Douglas fir .	$5{\cdot}76 \times 10^6$	2,505	2,600	1,730	173
Pre-stressed concrete .	$0{\cdot}63 \times 10^6$	382	580	580	145

* For the figures given in this Table, the Author is indebted to Mr G. M. J. Williams, M.A., A.M.I.C.E.

TABLE 4.—SPECIFIC STRENGTH—ENERGY ABSORPTION

Material	Bending $\frac{p^2}{Eg}$	Tension $\frac{p^2}{Eg}$	Compression $\frac{p^2}{Eg}$
Douglas fir	1·09	1·96	1·09
Pre-stressed concrete . .	0·23	0·23	0·23

TABLE 5.—SPECIFIC STRENGTH PER PENNY COST—STATIC LOADING

Material	Flexural rigidity $\frac{E}{dg^3}$	Bending $\frac{p}{dg^{1.5}}$	Tension $\frac{p}{dg}$	Compression $\frac{p}{dg}$	Shear $\frac{p}{dg}$
Douglas fir .	$0{\cdot}576 \times 10^6$	250	260	173	17
Pre-stressed concrete .	$0{\cdot}315 \times 10^6$	191	290	290	72

TABLE 6.—SPECIFIC STRENGTH PER PENNY COST—ENERGY ABSORPTION

Material	Bending $\frac{p^2}{dEg}$	Tension $\frac{p^2}{dEg}$	Compression $\frac{p^2}{dEg}$
Douglas fir	0·109	0·196	0·109
Pre-stressed concrete . .	0·115	0·115	0·115

CONCLUSIONS

Within the limitations of this analysis, and on the basis of the costs assumed, the more efficient of the two materials for the load conditions given, appears to be as shown in Table 7.

TABLE 7

Loading condition	More efficient material	
	By weight	By cost
	Static loading	
Flexural Rigidity	Douglas fir	Douglas fir
Bending	Douglas fir	Douglas fir
Tension	Douglas fir	Pre-stressed concrete
Compression	Douglas fir	Pre-stressed concrete
Shear	Douglas fir	Pre-stressed concrete
	Energy absorption	
Bending	Douglas fir	Pre-stressed concrete
Tension	Douglas fir	Douglas fir
Compression	Douglas fir	Pre-stressed concrete

" Pre-stressed Concrete Construction "

by

John Cuerel, B.Sc., M.I.C.E.

So much has been written and spoken about so many aspects of pre-stressed concrete during the past few years that there would appear to be little to add. Every engineer now knows what the material is, how it is utilized, and how to design in it. Its technical advantages have been widely proclaimed, and any author presenting a Paper on the subject is assured of a full house for its reception.

The enthusiasm of the apostles, the preachings of the specialists, and the propaganda of the groups, however, are not matched by the spread of pre-stressed construction. How far is this the result of relative economics?

Concrete for pre-stressed work requires to be of very high grade for the purposes of carrying stress, anchorage (whether by bond or bearing at an end anchor), protection against steel corrosion, and permanence generally. Quality is also necessary in normal reinforced-concrete construction, but it is thought that the average requirement in this respect is considerably higher in pre-stressed construction. Quality calls for first-class materials, organization, plant, skill, and honesty, and all these are expensive. High-tensile steel is normally used for stressing the concrete, generally in the form of drawn wire, the cost being about $2\frac{1}{2}$ times that of mild-steel wire.

Permissible working stresses in concrete and steel are considerably higher than in normal reinforced concrete. A compressive stress of 2,500 pounds per square inch is commonly used and this is a reasonable figure, having regard to the usual requirement that a cube strength of 5,000 pounds

per square inch must be attained on release of the wires, when the stress imposed on the relatively green concrete is often about equal to the maximum working stress. By virtue of an approximately doubled permissible stress, as compared with normal reinforced concrete, pre-stressed work should be advantageous as regards concrete cost, but it is necessary to bear in mind that in many structures it would not be economic to work to the maximum stress, also that the stress ratio tends to be unfair to normal work since this is closely governed by regulations. Pre-stressed construction enjoys a great advantage in permissible steel stress, this being about six or seven times the value for mild structural steel and round bars.

Taking merely drawing office factors into account, it could be held that pre-stressed concrete is the most economic material for a wide range of structures or structural members. Other factors than ability to carry loads, and first cost, are, of course, of great importance : the structure must be durable, it must be pleasing, maintenance costs must not be excessive, and the work must be capable of offering adequate resistance to hazards such as fire, sea-water attack, or others as may be appropriate.

Although restraint, on the part of the designer, is necessary in the majority of cases, there is little doubt that pre-stressed concrete scores well in the drawing office. Take, for instance, a bridge ; it might well be that, although pre-stressed concrete is the best material for the main beams, the foundations should be of mass concrete, the piers, abutments, secondary beams and decking of normal reinforced concrete, and the handrailing and lamp standards of metal. Given very high grade concrete (and this is assumed, for the purpose of this note, as essential), pre-stressed work is durable. The material is strong, and so, properly applied, it is capable of producing graceful and pleasing forms. Maintenance should be small by reason of good concrete, ease of providing adequate cover and elimination of cracks, and these same reasons ensure high resistance to corrosive attack. Its comparative resistance to fire is, perhaps, a moot point, and it is hoped that the discussion will throw more light on this aspect.

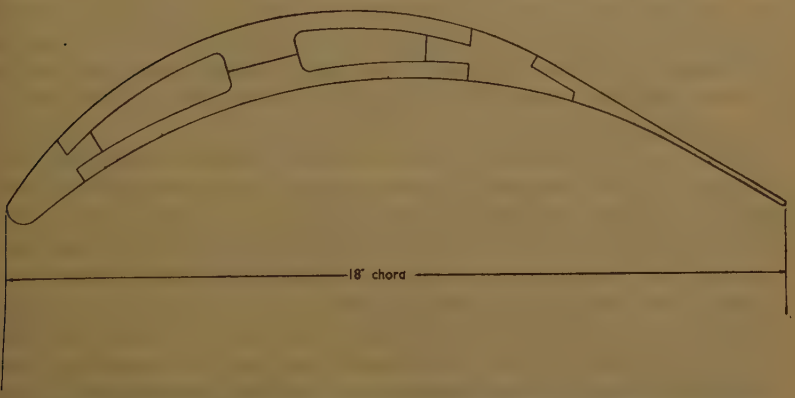
The question arises as to why, if it is, in fact, a relatively economic material, pre-stressed construction is not spreading more rapidly. It would seem obvious that the present-day shortages of materials and of up-to-date plant are potent factors. The difficulty of obtaining very high-grade concrete is undoubtedly another factor, but this arises not so much because of cost, but from inadequate training, lack of understanding, and absence of pride of craft.

Sooner or later, these difficulties will be overcome, and pre-stressed-concrete construction will blossom forth—if, in the meantime, it has not wilted because of an overdose of frustrated enthusiasm.

Discussion

Mr C. L. Champion said that when engineers were in a position to look at pre-stressed concrete work in retrospect, it might well appear that its greatest benefits to the art of structural design had been in forcing all concerned to produce a better concrete, and in introducing a spirit of scepticism regarding some of the regulations governing reinforced concrete construction. Probably most designers in reinforced concrete would say that, given the latitude enjoyed by designers in pre-stressed concrete, they could do things which they were unable to do at present. If there were complete assurance of a really consistent material, it would seem that either reinforced concrete or pre-stressed concrete could be introduced into fields hitherto hardly regarded as a part of civil engineering. Engineers were familiar with reinforced or pre-stressed concrete pressure pipes, but

Fig. 5



Vane Assembled from Five Light-alloy Extrusions Cemented Together

Mr Champion thought that the use of such materials might be extended to the large penstocks which were normally constructed in fabricated steel, and perhaps to pressure vessels such as those used in the chemical and oil industries.

It might seem at first sight somewhat strange that a vessel whose walls were in tension should be a suitable subject for the use of concrete, but the cost of high quality fabricated steel vessels, particularly if the welds had to be X-rayed, was so very high that there was opportunity for competition by other materials.

In the Note on light alloys the point had been made that one of the great economic advantages of light-alloy construction was that it was possible to obtain, comparatively cheaply, special extrusions suitable for

the particular job in hand, and it had been said that extrusions could be made in any shape that would pass through a circle of 15 inches diameter. That figure would appear to be a little on the high side but, even so, it certainly was a limitation in many fields of work. One simple way in which that could be overcome was by sticking together a number of extrusions with glue—a method used extensively in the aircraft industry —and modern synthetic glues could be relied upon to take the necessary shear.

Mr Champion quoted as an example a problem he had recently encountered. Specially contoured vanes—to divert an air stream—had been assembled from special extrusions cemented together with one of those glues, and, despite the considerable load on the vanes, the result had been satisfactory. A cross-section of one of the vanes was shown in *Fig. 5*. Construction in steel, machined all over, would have proved much more costly.

Dr F. G. Thomas observed that when new materials or new processes were being developed there was sometimes a tendency to try to use them for almost anything for which they were practicable. Engineers, however, made certain that the material was not only practicable but also suitable. In determining the suitability of a material for a particular purpose the engineer considered the technical and economical efficiency of the material for that purpose.

In recent years there had been many discussions on the technical merits and sometimes the technical disadvantages of pre-stressed concrete, but until that meeting there had not been a discussion on the economic side. It was for that reason that the Pre-stressed Concrete Development Committee of the Institution, of which Dr Thomas was the Chairman, had suggested that the meeting should be held.

Although he knew very little about economics, he was interested recently in a formula which had some bearing on the economics of any building construction. The formula, which had first been suggested by the Swedish engineer Kjellmann, could be expressed as follows :—

$$I + \Sigma R \times C = \text{a minimum}$$

in which I denoted the initial cost of the building, R the risk of a certain eventuality occurring, and C the cost of repairs or maintenance or even reconstruction involved by the particular eventuality occurring.

It had been rather disappointing to find in the introductory remarks to the Notes that emphasis was laid on initial cost rather than on the sum of the two terms of the formula. Would the Introducers give further information, particularly in connexion with the relative importance of the second term, compared with the initial cost ? For example, so far as maintenance was concerned Mr Shirley Smith had stated that money had to be spent every 7 years on painting a steel bridge. During the desired life of the structure, it could be presumed that it would have to be painted

a certain number of times and then the total cost of maintenance should be added to the initial cost before comparison with another material.

Technical questions arose regarding certain other eventualities, for example, fire. Mr Ratter had mentioned the question of fire risk and there was little information available with regard to pre-stressed concrete. It might be possible to determine, perhaps from the insurance companies, what risk there was that fire would occur in a pre-stressed concrete building or other structure and the cost of repairing such a structure could be assessed. It was possible—in fact probable—that the cost of repairing a pre-stressed concrete structure damaged by fire would be greater than the cost of repairing a reinforced-concrete structure which was similarly damaged, because of the difficulty of knowing what pre-stress had been lost, or what loss in actual strength the high-tensile wires might have suffered. It would be very interesting to have some data on those particular points, and Kjellman's formula would be useful in bringing the various possibilities into the right perpective.

Mr J. S. Campbell said that according to the Oxford dictionary the word " economics " meant management, and probably that was the right datum line from which to work in the discussion. In management of the type of matters under discussion every factor had to be considered—the factors of design, availability of materials, the economic condition of the country in the general sense, and the technical labour available to develop designs along the lines required.

There would appear to be no argument against the fact that the world shortage of coal and steel—which had been present for some time—would remain for quite a long time to come, and the shortage of those two important materials must exercise an influence. If the shortage of steel was going to persist, then alternatives had to be sought, and it was his belief that pre-stressed concrete, used in the correct manner, say, for a wide range of bridges, was the best material—whether there was a shortage of steel or not. Pre-stressed concrete, so far as the decking of a bridge was concerned, provided a complete distributing surface, and compared with the more orthodox type of construction, only one-seventh of the steel was used in pre-stressed concrete. In view of the present shortage, the great advantage to be gained from the use of pre-stressed concrete became apparent. Again, if that factor was considered in a time when there was no shortage, it would be found that the cost of steel in the building of a bridge constituted the major cost of the structure. Therefore, from the point of view of first cost in that sense the use of pre-stressed concrete was the cheaper method.

The question of maintenance had been mentioned and he had sometimes heard it suggested that no one had yet had sufficient experience of pre-stressed concrete to know just what were the various things which could happen to a pre-stressed concrete structure during its life. Experience had been gained of reinforced-concrete structures which had been

built about 50 or 60 years ago, and it was known that those which had been built under a good system of concrete control showed very good results indeed. It had been said before that the use of pre-stressed concrete was the better way of using concrete because it was a material which should not be subjected to tension, so that in the mechanical property which was given in the pre-stressing, the material was being used in the correct way. If good results, so far as maintenance cost was concerned, had been obtained from reinforced concrete over a number of years, then it was only fair to assume that there would be similar good results from the use of pre-stressed concrete.

Mr Cugrel had stated in his Note : " It might well be that, although pre-stressed concrete is the best material for the main beams, the foundations should be of mass concrete." It was to be assumed (from his oral introduction) that Mr Shirley Smith agreed that pre-stressed concrete was the best material for the main beams of a bridge.

Mr. Shirley Smith was concerned about the possible difficulty in exporting steel if there were a sudden switch over to pre-stressed concrete in Great Britain. That might not be such a sad day because the steel could always be used in the making of jacks, bearing plates, and other equipment for making pre-stressed concrete !

Mr D. H. New said that it would, of course, be foolish to suggest any complete turn over to pre-stressed concrete, and the real question before the designer was whether he should or should not add pre-stressed concrete to his list of economic building methods, and many had already decided in favour.

According to records of the Pre-stressed Concrete Development Group, the total stressing-bed capacity of the twenty-six firms in Great Britain now engaged in the production of pre-cast pre-stressed units would be increased by 58 per cent by the end of 1952. That, in conjunction with the many schemes involving on-site pre-stressing, clearly indicated the general trend, and in view of the national necessity, it was hoped that those in control would ensure adequate supplies for all projects which could be carried out in that medium in order to free steel for defence and the export industries. Time had left no doubt regarding the economies possible with normal reinforced concrete construction, and as Mr Snow had stated, pre-stressed concrete was only a natural development in its design.

The designer intending to use reinforced concrete now had, in fact, three tools in his hands instead of one ; normal reinforced concrete, end-anchored pre-stressed concrete, and fully-bonded pre-stressed concrete, and it was up to him to use those three tools skilfully for the production of an economic structure.

As an example, the new hangars for the British European Airways, London Airport, had proved to be an outstanding example of the harmonious blending of the various types of construction to give a highly competitive design. The foundations, columns, and walls, and some beams and

slabs were in reinforced concrete, and the main beams of the hangar of 110 feet and 150 feet clear span were in end-anchored pre-stressed concrete. Repetition floor and roof beams were in fully-bonded pre-stressed concrete. Some floor joists and purlins were in pre-stressed concrete. The crane beams and the main members of the temporary floor were in steelwork, the lightweight roofs in aluminium, and there was timber for the shuttering. It had to be borne in mind that that design was evolved in direct competition with other forms of construction. It was well known that pre-stressing had made a direct saving on many contracts, especially those involving piles, and in that connexion the breakage of pre-stressed piles, where they had been adequately designed, was infinitesimal, but it could not be over-emphasized that it would only be economic if used in the right place.

Mr Ratter had suggested that little was known of the fire risk of pre-stressed concrete, but in fact one floor on the market which had been tested, incorporating a 6-inch-by-6-inch pre-stressed concrete beam constructed composite with the floor, held a certificate from the Fire Research Station at Elstree for a 2-hour fire test, which was more than sufficient for general requirements. The cover was just less than 1 inch and the 6-inch-by-6-inch beam entirely unplastered. Some of the $\frac{1}{2}$-inch-thick plaster on the underside of the floor fell off soon after the test had commenced.

Mr Shirley Smith had stated that steelwork got a flying start because it could be fabricated in the shops while foundations were being prepared on the site. Whilst that might have been true at one period, the modern methods of pre-casting often gave a similar advantage to reinforced and consequently pre-stressed concrete. It was known that reinforced concrete was normally more economical than steel for multi-storey buildings, and to those who looked upon pre-stressed concrete as a natural development of reinforced concrete the inference there was obvious.

There were no grounds whatsoever for assuming that corrosion problems in pre-stressed concrete would be serious; in fact, all evidence pointed the other way.

With regard to shock, the fact that highly stressed wires might snap at their ultimate load like over-taut violin strings was irrelevant, since presumably steel would also fail when it reached its ultimate load and, at all events, the general case was for the concrete to fail first.

So far as aluminium was concerned, as was indicated by Mr Pike in the fourth paragraph of his Note, Mr New considered that the field of competition between the two materials was extremely limited and that one would normally be complementary to the other.

Mr Reece had given some very interesting figures for comparison of Douglas Fir and pre-stressed concrete, and in Table 7 he had produced some evidence that, with regard to cost, pre-stressed concrete was more efficient than Douglas Fir.

It should be emphasized that the real consideration was not that pre-stressed concrete was economical to use in all cases, but that it was a rational medium of construction which could be usefully added to those already in use.

The fairly recent (although not new) advance in technique should be accepted and exploited, and from purely economic considerations Mr New urged all those engaged in construction and design to give serious thought to the use of pre-stressed concrete in positions where it appeared to have advantages. At the same time, it should not be forgotten that here was one way in which engineers could make a direct contribution to the national economy—by freeing steel for export.

Mr J. R. Liversedge said that the relative economics of structures at the present time undoubtedly depended upon two factors. The first was the availability of materials and the second was cost. Various phases of scarcities were experienced periodically—bricks, cement, steel, and then back to something else. Therefore, it was very difficult indeed to make a lasting comparison between those structural mediums at any particular time. It was necessary for engineers to review availability and costs at considerably more frequent intervals than had been the case in pre-war days, and Mr Liversedge felt that the two most important problems at the present time were how to save coal and how to save steel; in that respect it would appear that reinforced concrete was the best saver of steel.

In developing those relative positions the cost of pre-stressed concrete should be given in relation to other costs. He had gone very carefully into the relative cost of pre-stressed floors and beams, but he still remained unconvinced that, on behalf of the client for whom the engineer was working, pre-stressed concrete could satisfy the cost requirement; therefore, until it could be shown to do so, reinforced concrete would, in his view, remain the leader of the materials under discussion.

Mr S. R. Banks, speaking on behalf of aluminium, said that the discussion was very well chosen at the present time. In the Notes and there had been evidence of a very honest commercial urge by each proponent to prove that his material was pre-eminently suitable for almost anything. That competitive approach was a sound way to engineering progress and it was gratifying to see it.

There were, of course, obvious reasons why pre-stressed concrete would not be recommended for use in the construction of an aircraft any more than aluminium would be used for the counterweight of a bascule bridge. Nevertheless, in the present situation it was well worth looking around and assessing all the possibilities for efficient and rapid construction.

Mr Ratter's list of economic factors was a very useful yardstick and it might be convenient to use it with aluminium as the subject. Although it was a costly material and a dollar import at that, so far as Great Britain was concerned, aluminium was entirely a Commonwealth product; and it was inconceivable that the Canadian dollar would remain the almost

insurmountable obstacle to the pound sterling that it was at present. Steps would be taken within the Commonwealth to prevent that and, indeed, the British Government had investments in Canada at the present time with that object in view. In spite of the dollar drawback, the price of aluminium had increased less rapidly than any other materials under discussion. The price of aluminium ingot, in February 1952, was 1½ times that in 1938, and by comparison, billet steel was 2½ times as expensive, cement had more than doubled in price, and timber cost 3 or 4 times as much as it had done before the war. If that relative trend continued it was perfectly clear that aluminium should come more and more into structural use, and for the benefit of some of the Introducers it might be noted that no coal was required for the production of aluminium !

Mr Ratter's fifth point concerned the question of availability, which was a comparative newcomer in the field of structural economics. In ordinary times availability was entirely secondary to suitability and to price, but today it had become of great importance. Availability had already had a pronounced influence on aluminium, and had been of great value to the aluminium industry in enabling experience to be obtained despite price disadvantages.

At the moment, of course, aluminium was subject to the stumbling block of non-availability, and there were two reasons for that. The first was that the armament programme used a very large percentage of all the aluminium obtainable in Great Britain and, secondly, it had been necessary to trade 25,000 tons of aluminium for 1 million tons of steel. That situation was only temporary and would surely ease because of the steps taken by the aluminium industry to increase smelter capacity. It had been reported in February, 1952, that by the end of the next year American capacity would have nearly doubled ; and similar steps were being taken within the Commonwealth. In Canada a new smelter was being built, to be in operation in 1953 ; and if the proposal for another smelter in the Gold Coast went forward, by the time those two smelters were in operation the production within the Commonwealth would also have nearly doubled.

One point which was not contained in Mr Ratter's list was that of technical acceptability. In that context aluminium was a comparative newcomer and the attitude of the professional engineer was quite rightly cautious. The low modulus compared with steel, the absence of a yield point, the unimaginative range of standard shapes in juxtaposition to the limitless variety of extrusions available—all those factors called for high competence in design. Considerable progress was being made, however. Within the past year much had been done so far as riveting and welding aluminium structures were concerned, and more was likely to be heard about that in the future. New functional standard shapes were being worked out, and confidence in the material was growing, an example being the Dome of Discovery.

Mr Banks exhibited several slides depicting large constructions in aluminium, and said that painting had not been considered necessary for the 290-foot aluminium arch bridge at Arvida, Quebec, where experience had so far shown that corrosion did not occur; cold-driven aluminium rivets had been used throughout.

[Two of Mr Banks's slides are reproduced in *Figs 6* and *7*, facing p. 395.]

Mr C. V. Blumfield said that, in spite of Mr Banks' very convincing facts and figures with regard to aluminium, his own feeling was that at the present time, and for some time to come, the two principal protagonists were structural steel and reinforced concrete with its development into pre-stressed concrete.

It was a little disappointing to discover, on reading the Notes under discussion, a certain vagueness about the arguments put forward. Comparing the use of structural steel and reinforced concrete in certain structures, he had found from experience that in a number of cases before the war multi-storeyed buildings showed a saving of 20 to 25 per cent in the use of reinforced concrete as against cased structural steel. Admittedly that was using reinforced concrete at its most economical advantage. If the job had to be organized to keep pace with structural steel, the extra cost reduced the saving to something like 15 to 20 per cent.

Turning to roofs, the structural-steel roof with an asbestos covering was undoubtedly the cheapest construction over large spans; but under present conditions there were very few structures, apart from cowsheds and timber storage, for which it was much used. It was very essential that every building should be designed to save coal as much as possible, and that was done not only on the first cost, but by making a properly insulated building.

After many comparisons Mr Blumfield had found that shell concrete compared very favourably with structural steel, provided that the standards given by the alternative methods were similar; in other words, that the steel was brought up to the same level of amenities, appearance, and insulation, as the shell concrete.

Regarding pre-stressing, there were, of course, two types of pre-stressing—pre-cast pre-stressing and the post-tensioning technique. Mr Blumfield felt that although pre-cast pre-stressing was useful on such things as sleepers, etc., the eventual success of the construction was not necessarily achieved by endeavouring to imitate structural-steel beams. When the emergency was past, in all probability very few people would prefer the pre-cast beam to the steel beam, provided the cost and availability were comparative.

In respect of post-tensioning it was felt that for work on the site it was too early to give any definite figures with regard to its relative economy. The prices which were being quoted by contractors for post-tensioning were really experimental. The attitude of mind of most contractors was probably " This is new; let us have a go " and jobs were priced without

keeping to the normal profit margin. Until a number of years had passed and the economics had been worked out, it was difficult to formulate any positive arguments. So far as long-span concrete shell structures were concerned, Mr Blumfield felt that there was definitely a field of economy in post-tensioning. He had found that in the construction of north-light roofs, post-tensioning of shell concrete permitted methods which would otherwise have been impossible.

Mr J. M. Smith observed that the introducers appeared to be fighting unnecessarily because, after all, in most cases the nature of the job itself decided the type of construction. It was in connexion with the borderline cases that several types of construction tended to compete.

Mr Smith suggested that there were possibilities of marriages between pre-stressed concrete and aluminium. In fact, he could cite two fairly large jobs which had been carried out economically in that way. In one case the economy had been effected where gantry stanchions were used in bending and the total load was rather too much for aluminium to be economical; it had been worth while incurring the cost of pre-stressing, which had also facilitated the assembly of the plant. The other case concerned portal frames; structures had been made entirely in aluminium but there was a case for using pre-stressed concrete legs with an aluminium roof, particularly where the spans were large.

He would point out to Mr Ratter that aluminium construction was no novelty, because Mr Smith's firm had made several hundred aluminium structures during the past 4 years in Great Britain and abroad, and they had not been standard buildings, but "made to measure."

Mr Smith then showed some slides illustrating the erection of portal frames for a large hangar at London Airport. The main members had been loosely bolted at each joint and the bases positioned and hinged on the ground. From a collapsed position each pair of half-portals complete with purlins, stays, and bracing was hoisted into a vertical position by two 3-ton winches, and final connexions were then completed.

Much had been said about maintenance in connexion with aluminium, and there was no doubt that in inaccessible structures it became an item for consideration. One particular alloy, AW10, which was normally used, was very rarely painted. In fact, he knew of only one structure which had been painted and that was for a special reason.

Another important point, apart from the cost of maintenance, was that certain factories, such as food and chemical factories and weaving sheds, could not in any circumstances have rust dropping on their processing, and for that reason aluminium trusses could be justified.

Mr F. J. Samuely observed that most of the Introducers disagreed with each other so far as their own material was concerned, but agreed when it came to condemning all the other materials! So far as he was concerned, Mr Samuely disagreed with all the Introducers because it was absolutely impossible to state that a material had some definite advantages

over other materials. Every one of the materials mentioned had their use at the present time. In the past few years he had been associated with reinforced-concrete structures, pre-stressed concrete structures, steel, aluminium, timber, with pre-stressed brickwork and pre-stressed timber, but it was difficult to say that any one of those materials was uneconomic.

How did one go about finding out whether a certain material was suitable and economical in a special case ? It was impossible to set about buying the different materials before coming to a conclusion. There were a few yardsticks. For instance, it could probably be said that for multi-storey building, steel could not be considered economical unless time of erection was of prime importance.

Mr Samuely said that he could illustrate the comparative prices of materials, as near as was possible in present times, by giving a few figures which he had abstracted. For instance, a beam of 24 feet span, with 40 lb. per foot load, in reinforced concrete would cost 19*s.* to 24*s.* per foot run. In pre-stressed concrete the cost was 19*s.* to 25*s.*, so both those prices were practically the same, although he would give preference to pre-stressed concrete because of the small amount of steel used. Such a beam in steel cost 49*s.* 3*d.* to 53*s.* 9*d.*, which showed a considerable difference in cost. For a 40-foot beam in a similar case the cost in reinforced concrete was 32*s.* to 41*s.* 6*d.* and in pre-stressed concrete, 35*s.* to 44*s.*, which was slightly more expensive than reinforced concrete. The same range in steel was 63*s.* to 71*s.* That showed that beams could be constructed more cheaply in reinforced concrete than in steel, and could be constructed in pre-stressed concrete for practically the same price as in reinforced concrete but using much less steel. So far as columns were concerned, the results were similar but one would not use pre-stressed concrete for columns unless bending moments were very large.

Mr Samuely would not agree that concrete was necessarily the cheapest material for roof work. He had found that it was cheaper to have a steel construction if there were a light material to cover it. There was little doubt that, so far as buildings of large spans, say 150 feet to 200 feet, were concerned, concrete could not really compete. At the same time he had used pre-stressed timber to very great advantage and that had proved to be the cheapest construction in certain cases.

Therefore, it could be said that for each type of building there was one economic type of structure, and so far as pre-stressed concrete was concerned, in his view that had definite advantages in multi-storey buildings and in shell construction.

As for fire proofing, Mr New had mentioned one test. Another test had been carried out at Elstree and the result had shown that there was no reason to assume that pre-stressed concrete was any less fire-proof than reinforced concrete.

Mr R. D. Binns said that although the subject under discussion concerned the relative economics of pre-stressed concrete, it seemed to have

developed into a discussion on the structural safety of pre-stressed concrete.

Mr Shirley Smith had stated in his oral introduction that the steel in a suspension bridge was stressed to 30 tons per square inch, but in pre-stressed concrete it reached 65 tons per square inch. That appeared to involve the question of fatigue.

In pre-stressed concrete the stress varied little between the full-load condition and the unloaded condition, whereas in a normal suspension bridge the range of stress, upon which fatigue depended, might be quite considerable.

With regard to corrosion, it was important in pre-stressing that the concrete should be of very high quality, otherwise it would fail at the stressing stage. Pre-stressing and high-quality concrete thereby reduced the risk of corrosion.

On the question of economics, Mr Binns had been associated with a firm manufacturing pre-stressed concrete for the past 3 years, and although endeavours had been made to say that certain types of units were economical in pre-stressed concrete it had been difficult to dogmatize. The cost of a beam had, on occasions, been compared with other methods of construction and had been found to be lower, but on quoting for another almost identical job it had been found to be higher.

Pre-stressed concrete was still in its infancy, and at the present time it was impossible to make a generalization as to whether it was economical or not. Each job should be judged on its own merits.

Mr P. S. A. Berridge, referring to Mr Cuerel's closing remarks in his Introductory Note, said he did not think pre-stressed concrete had yet wilted because of an overdose of frustrated enthusiasm. But with so little knowledge of its behaviour and no experience of the life of bridges made of pre-stressed concrete, he thought that the subject was in urgent need of more research. The discussion was on the relative economics of pre-stressed concrete compared with other forms of construction and, since there was nothing definite to show how long pre-stressed concrete structures would last, it was difficult to make a really fair comparison.

With regard to failure by fatigue, the increment of stress due to live load in the pre-stressing wires or bars of a bridge was very small, and that was a good reason for expecting long life from pre-stressed concrete. Moreover, the working stresses in the wires or bars would, after the loss due to creep and so on, never approach the stresses to which steel had been subjected at the time of pre-stressing.

Nevertheless Mr Berridge felt sure that, for spans exceeding 30 feet, railway engineers would prefer to build bridges in steel if they could get it, because not only had its life been proved but steel girders were so much more convenient to erect and indeed to alter later on if the bridge had to be moved, widened, etc.

He also thought that not enough attention was paid in Great Britain to the re-use of serviceable girderwork still in good condition after release

from bridges made redundant through the closing of lines. He had recently had occasion to consider what to do with the girderwork of a 150-foot span, the steel of which was in excellent condition. The rivets would have cost more than 3*s*. each to cut out by the method of drilling and knocking off the heads and punching out the shanks. On the North Western Railway in India where the re-use of serviceable girderwork had been much practised, rivets had been cut out very much more quickly and cheaply with pneumatic rivet-busters. He thought that the use of these machines in Britain would make the re-use of such girderwork an economic proposition and result in an appreciable saving of steel.

Mr D. V. Pike, in reply, said that he agreed with the opinions expressed by some of the engineers who had spoken that all the materials now in use should be exploited to the full, that the very best should be got out of them, and that the appropriate materials should be used in the particular conditions.

He recalled in his younger days, when reinforced concrete was claiming the attention of engineers even more than it was at the present time, hearing a lecturer state that in the future he expected to walk up a reinforced-concrete road into a reinforced-concrete house, up some reinforced-concrete stairs to sleep in a reinforced-concrete bed. Mr Pike's reaction had been that he did not wish to hear any more about reinforced concrete for a long time.

Dr Thomas's remarks regarding maintenance were very important and perhaps they could usefully be linked with another point which had not been taken into account, namely, the cost of taking down reinforced concrete.

It had been suggested that there was not much aluminium to be obtained anywhere at the present time and that other means of saving steel would have to be sought; but it was necessary to emphasize that steel was being saved by the use of aluminium for structures for the Services. Quite a lot of structures were being made in aluminium which were previously made in steel and it was expected that the supply situation would now be quickly improved.

Mr F. S. Snow, in reply, said that Mr Smith had asked how it was possible to repair the concrete with all the spalling which occurred. Mr Smith should know that the cause of that spalling was the use of flat stirrups for reinforced concrete work; nobody with any knowledge used flat stirrups now. Had it been because of the great desire of the steel people in those days to sell their steel? It was easier to repair reinforced concrete than anything else, and there was a very successful system known as "Guniting."

Mr Smith had also referred to the question of cost. If he would think in terms of the carrying capacity of a ton of cement made into concrete and compared that with steel for the same carrying capacity, and the amount of coal used in manufacture, he would see what Mr Snow was getting at.

Dr Thomas had given a long address and had concluded by saying that he wanted some information. It was necessary to remind Dr Thomas that he was in the Building Research Station to which those present subscribed, and it was up to him to give the information that he had requested.

As had been stated by several speakers during the discussion, the real problem facing all engineers was to utilize the materials available for any particular structure in the most economical and practical manner possible, and in so doing one had, of course, to use all the materials which had been discussed in their respective position in the structures.

So far as the question of true rational economics was concerned—the saving of steel and coal—there was no doubt that reinforced concrete had an advantage over every other type of material, and possibly in the future when many more tests had been carried out, especially with regard to fire and corrosion, pre-stressed concrete in its turn would possibly supersede a lot of the reinforced concrete work.

The demand for steel in Great Britain for export and use at home considerably exceeded the supply, but if the reinforced concrete industry could be given another 100,000 tons of billets, it could in turn produce three times more structures than was possible under the present system, with the result that there would be three times more work under construction. The irrefutable claim put forward on behalf of reinforced concrete at the present time was that it was more economical than any other material.

Mr H. Shirley Smith, in reply, observed that only Mr Binns and Mr Berridge, in their most interesting contributions to the discussion, had attempted to justify the high working stress of 65 tons per square inch used in cold-drawn wire in pre-stressed concrete, whereas identical wire was only stressed to about 35 tons per square inch when used in the cables of long-span suspension bridges. Mr Shirley Smith could not agree, however, with Mr Binns's suggestion that the variation of stress in the wire between the loaded and unloaded conditions was much less in pre-stressed concrete than in a suspension bridge. The full live load on a suspension bridge was rarely responsible for more than one-fifth of the cable stress; furthermore, tests showed that the weight of traffic covering a bridge seldom exceeded a quarter of the full live load; the variation of stress in the cables of a suspension bridge would only very exceptionally be more than 5 per cent, which was of the same order as the variation occurring in the wires of a pre-stressed concrete bridge. Mr Shirley Smith could see no justification, therefore, on grounds of absence of fatigue, or indeed on any other grounds, for so drastically reducing the factor of safety in pre-stressed concrete design.

Mr Berridge had suggested that the working stress in the wire would, after losses due to creep, etc., never approach its initial stress; but if that were true, and the stress in the wire were to fall much below 65 to 60 tons per square inch, surely the whole basis and purpose of pre-stressing would be destroyed?

Mr Shirley Smith had been impressed by the example that Mr New had quoted of the harmonious use of the various materials under discussion at London Airport. There was no doubt that, subject to certain reservations, each had its place in economic design. The liability of the highly-stressed wire in pre-stressed concrete to fail under shock was, however, one of the reservations. The point was that the working stress in that wire was about two-thirds of its ultimate strength, whereas the working stress in bars in reinforced concrete was less than one-third of their ultimate strength. The wire, therefore, had less than half the margin of safety that the bars had, and would be correspondingly more liable to failure under shock which caused a sudden accession of stress.

In reply to Mr Campbell, Mr Shirley Smith said that he was by no means convinced that the present shortage of steel would persist. The tonnage of steel allocated to structural work was a very small percentage of the total steel production, and the balance between supply and demand was very fine. The use of steel was so varied and its production so immense that a slight change in world conditions might at any time turn a structural shortage into a surplus. With regard to any economy to be gained by using pre-stressed concrete for the main beams of a bridge, to which Mr Campbell had referred, Mr Shirley Smith thought that he had made his views clear in his Introductory Note.

It was encouraging that so many speakers had underlined the necessity for high-quality concrete to avoid heavy upkeep costs and risk of corrosion. He thought that Waterloo Bridge was an outstanding example of the fine quality of concrete that it was possible to obtain to-day, both in appearance and in freedom from any kind of flaws. No doubt the precautions to be taken to produce such concrete added to its cost, but in Mr Shirley Smith's opinion, it was worth it every time.

Mr Banks had imparted some startling information, for Mr Shirley Smith had never realized that aluminium was now so costly that only 25,000 tons of it was required to pay for 1 million tons of steel!

Mr Champion, in his comparison of the cost of welded steel and pre-stressed concrete pressure-vessels, had referred to the necessity for X-raying the welds in the steel. In Mr Shirley Smith's opinion it was equally necessary to X-ray the concrete, because it also was subject to manufacturing faults. If that was included, the comparison of costs would show a very different result. With regard to the laminated vane of five light-alloy extrusions exhibited by Mr Champion, could a component made in that way stand up to all the conditions of everyday use without risk of failure of the glue or cement?

Mr P. O. Reece, in reply, observed that Mr Banks had made a quite erroneous statement in asserting that timber cost three or four times as much as it had done before the war; in point of fact it cost seven times as much!

It was difficult, however, to see how Mr New interpreted Table 7 to show

that pre-stressed concrete was more efficient than Douglas Fir; it was for certain purposes but not for most.

Mr Reece said that he had made a comparative analysis for most structural materials, and if it were of any satisfaction to the pre-stressed concrete advocates, he would say that it was more difficult to present a good case against pre-stressed concrete than against any other material. Mr Reece also admitted that he had no very strong feelings on the matter because, having seen a few reinforced-concrete jobs and having discovered that they used more wood than if the structure itself had been made of timber, there was not a great deal of point in arguing!

He was disheartened at the complete lack of interest in a rational method of making a comparison. Mr Samuely had agreed that some yardstick was necessary but had failed to describe that yardstick. The whole question hinged on ratio of intensity of loading to a critical dimension. It could be worked out in a general way for any structure. To take one example, it would probably work out as followed in a multi-storeyed building: the lower floor in steel, the next in reinforced concrete, the intermediate in aluminium, and the top floor in timber. It would perhaps be a funny building but it might be good engineering!

Mr Reece wished to emphasize the availability factor. Timber was really the only material which would be readily available. Apart from that, the right use of the right materials on a rational basis was the goal at which to aim.

Mr J. Cuerel, in reply, questioned Mr Shirley Smith's statement that pre-stressed wire was worked at twice the stress at which similar wire was worked in suspension bridges. It was not; the usual working stress was about 55 tons per square inch after losses, and Mr Cuerel suggested that modern suspension bridges often used a wire stress of considerably more than 30 tons per square inch. There were, however, good reasons why the wire stress in pre-stressed concrete could safely be higher than in a suspension bridge. After a pre-stressed concrete structure was built the wire stress remained reasonably constant at a value less than originally applied and so there was a high probability of greatly reduced fatigue. Further, there was not the same need to be concerned about corrosion, for several inches of high-grade uncracked concrete afforded a better protection than a coat of paint.

With regard to fire risk, Mr Cuerel was comforted by the remarks of Mr New and Mr Samuely. That aspect did, however, call for more research and there was need for full-scale practical tests.

A lot had been said about aluminium and it was interesting to learn that much of it was produced in the sterling area of the Commonwealth; but it should be pointed out that all the materials in pre-stressed concrete were produced in Britain and required no dollars of any sort. Some very interesting slides had been shown of aluminium construction, which must have caused some concern to the supporters of structural steel, but greater

economy would have been effected if pre-stressed concrete had been used. The price of aluminium per ton was about four times that of high-tensile steel wire and the stress to which the best of it was worked was only one-sixth that of the wire. Allowing for a three-fold difference in weight there was an adverse factor of eight—how then could aluminium compete with pre-stressed concrete ?

Mr Berridge has mentioned a preference for steel for railway bridges of moderate span. Structural steel might well have some use in bridges of more than, say, 200 feet span, but the great bulk of railway bridge work was in much shorter spans, and for them steel had no real case, except perhaps conservatism, and even so the discussion had shown that another railway bridge engineer had been converted to pre-stressed concrete for small bridges.

It would appear that the concluding remark in Mr Cuerel's Note had been misunderstood. The wording was "*if*, in the meantime, it has not wilted. . . ." Mr Cuerel did not forecast that it would wilt because there seemed to be no lack of enthusiasm at all, despite the frustrations that had arisen owing to the shortage of wire.

Mr Cuerel was almost as catholic in his use of materials as Mr Samuely, and he had not suggested and did not suggest that pre-stressed concrete was best for every structure in all circumstances. He felt sure, however, that the discussion had shown that it was greatly superior for a large number of structures to any other material mentioned.

Paper No. 5852

"Problems in the Design and Construction of Knockendon Dam"

by

James Arthur Banks, O.B.E., M.I.C.E.

(*Ordered by the Council to be published with written discussion.*)†

SYNOPSIS

Two reservoirs in Scotland, Knockendon and Muirhead, were under construction concurrently in the same locality. Both dams were designed for the same maximum height, 90 feet, and were to be earth embankments formed of boulder clay of similar characteristics. Knockendon dam, which forms the subject of this Paper, was modified during construction in the light of experience gained at Muirhead, to which comparative reference is made. Before Muirhead dam was completed, movement of the earthwork occurred and remedial measures, which included limiting the height of the dam to 70 feet, had to be adopted, whereas the modifications which it was possible to introduce at Knockendon at an earlier stage enabled Knockendon dam to be constructed to its full intended height of 90 feet.

Particulars are given of the initial investigation at Knockendon which determined the modified design, and of a subsequent investigation to ensure that the anticipated strengths in the embankment were being maintained. Observations were taken of pore-water pressures in the boulder clay and an analysis is given of the probable stability of the embankment, based on these results.

A salient factor in the relative stability of the two dams was that whereas Knockendon dam was constructed slowly, the rate of construction of Muirhead dam was greatly accelerated, and reference is made in the Paper to the possible effect on earth dam design of the rapid rate of construction achieved by the use of modern muck-shifting plant.

Introduction

Knockendon is one of the impounding reservoirs of the Irvine and District Water Board and lies within the catchment area of another of the Board's reservoirs—Caaf. An Order obtained in 1902 authorized the construction of two impounding reservoirs on the Caaf Water, but only Caaf reservoir was undertaken. It was inaugurated in 1906. Thirty-five years elapsed before a final decision was made to fulfil the original intentions, and in August 1938, the Board place a contract for the construction of Knockendon reservoir, to be completed in 3 years.

† Correspondence on this Paper should be received at the Institution by the 1st November, 1952, and will be published in Part I of the Proceedings. Contributions should be limited to about 1,200 words.—Sec. I.C.E.

The Caaf Water rises in the hills above Fairlie on the Firth of Clyde and is a tributary of the River Garnock which it joins near Dalry. The catchment area of Caaf reservoir extends to 2,576 acres and, of this, 1,540 acres drains, or is diverted, into Knockendon reservoir. This new reservoir has a storage capacity of 450 million gallons and, when filled to overflow level, has a water-surface area of about 70 acres. The overflow sill is at + 742·00 O.D. The long-term average rainfall over the gathering ground is 56 inches per year, and, with the storage which Knockendon reservoir affords, the water supply available to serve the Board's consumers has been increased by 2½ million gallons per day.

Water-Supply Systems of the Irvine and District Water Board and of the Corporation of Paisley

The water-supply systems of the Irvine and District Water Board and of the Burgh of Paisley are closely related. Trunk mains feed from the Corporation's Camphill reservoir into the Board's Munnoch reservoir, and water can thus be supplied from the Paisley system to Irvine and District. Gravitational circumstances do not allow these facilities to be reciprocated, but any increase in reservoir storage or in demand in the one area is reflected by the supply available to the other.

Knockendon is situated three miles to the south of the Corporation of Paisley's Muirhead reservoir. Both of these reservoirs were under construction at the same time. The works were of national importance because of industrial requirements in the respective areas and, when war broke out in 1939, the question of accelerating progress with one or both of these schemes had to be decided.

Muirhead is situated alongside a public highway. There were no pronounced changes in contour either in the solum of the reservoir or at the site of the dam, so that the conditions as a whole were favourable for access and rapid construction. On the other hand, Knockendon reservoir is in a more remote location and access to the site is by a service road (constructed under the contract) which extends for about ½ mile from a moor road over the hills between Dalry and Fairlie. Access was therefore much less favourable than at Muirhead. Also, at the site of the dam, the Caaf Water runs through a deep and somewhat narrow gully, and there was a limit to the amount of plant that could operate until the embankment had been raised above the shoulders of the gully. After full consideration, it was decided to accelerate construction of the Muirhead dam, whereas it was deemed impracticable to hasten the programme of work at Knockendon. The outcome of this decision was that Muirhead dam was completed very rapidly, whilst work at Knockendon proceeded more slowly than had previously been anticipated; in fact the Knockendon reservoir was not inaugurated until October 1947.

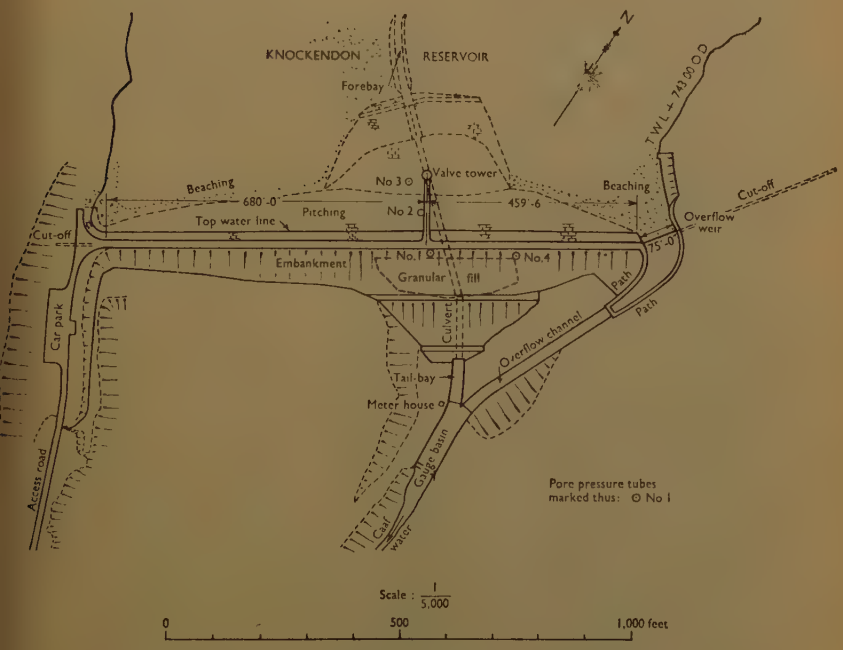
It transpired that experience gained at Muirhead was to have a very

significant influence on the design and construction of the dam at Knockendon. The Muirhead works have been the subject of Papers previously published,[1] and in this Paper the Muirhead dam will only be described sufficiently to explain its influence on the construction of the Knockendon works.

General Description of Knockendon Works

A general plan of Knockendon dam as finally completed is indicated in *Fig. 1*, and a cross-section is shown in *Fig. 2*. These both show modifi-

Fig. 1



General Plan of Embankment and Outlet Works

cations to the original design, which will be referred to later. The dam is an earth embankment with a maximum height of 90 feet. It is about 1,300 feet long, but the high portion of the embankment extends only across a gully through which flowed the Caaf Water. Except for the gully portion,

[1] J. A. Banks, "Construction of Muirhead Reservoir." Proc. 2nd Int. Conf. Soil Mech. & Foundn Engng, 1948, vol II, p. 24 (IV b 3).

J. A. Banks, "Problems in the Design and Construction of Muirhead Reservoir." Read before Edinburgh Assocn I.C.E., 10 Jan. 1951.

the height of the dam does not exceed 35 feet. The top width of the dam is 15 feet. The upstream face, which is pitched with stone, has a 3:1 slope, and there is a very substantial berm at approximately mid-height, as may be seen in *Fig. 3*. This berm was not included in the original design but was added while work was in progress. The downstream face of the dam, which was sown with grass, has a $2\frac{1}{2}$: 1 slope with a 10-foot berm at about mid-height.

Stone rubble walls form the toes of the slopes, and liberal provision was made for internal drainage in the outer half of the downstream side of the embankment. A continuous 2-foot layer of quarry debris was laid at the base, and vertical dry stone walls were built, spaced 50 feet apart. The granular fill on the downstream side, shown in *Figs 1* and *2*, was not part of the original design.

The geological formation at the site consists of boulder clay overlying sandstone. A concrete wall with cementation forms the cut-off below ground level, and above ground level a puddle clay core is incorporated in the embankment. The embankment was formed of the boulder clay excavated from borrow pits, partly within the solum of the reservoir adjacent to the dam. The same material, selected from the more clayey deposits and with the larger stones removed, was used for the puddle clay core.

A culvert for diversion of the stream during construction of the dam was founded on rock throughout its length. It was designed as a geostatic arch with a sectional area approximately equivalent to a circle of 8 feet 6 inches diameter. The location of the culvert is adjacent to the natural course of the stream and is shown in *Fig. 1*. The bend on the downstream length was necessary because of the restricted space in the gully.

The overflow weir of the reservoir is 75 feet long, this dimension being determined in anticipation of a 3-foot rise in water level with normal maximum flood. The invert of the overflow channel follows approximately the natural slope of the hillside and has a maximum gradient of 1 in 3, The gauge basin, which takes the outflow from the reservoir, serves as a stilling pool for flood waters conveyed by the overflow channel. The tail-bay and the lower end of the overflow channel are shown in *Fig. 4*.

Fig. 5 shows a longitudinal section of the dam with the vertical scale $2\frac{1}{2}$ times the horizontal scale. The formation of the ground surface, including the gully at the Caaf Water, can be seen, and the Figure also shows the depth of the concrete cut-off wall and the cementation bores. At the east end of the dam the line of the cut-off was changed in direction, as indicated in *Fig. 1*. This was done to take the optimum advantage of ground and rock contours, and to avoid a small gully immediately to the south. The average depth to the bottom of the cut-off wall, measured from ground level, is about 43 feet, and the depth of boring below the bottom of the trench ranged from 90 feet at the centre to 50 feet at the

Fig. 3

KNOCKENDON DAM. UPSTREAM ELEVATION

Fig. 4

KNOCKENDON DAM. OUTLET WORKS

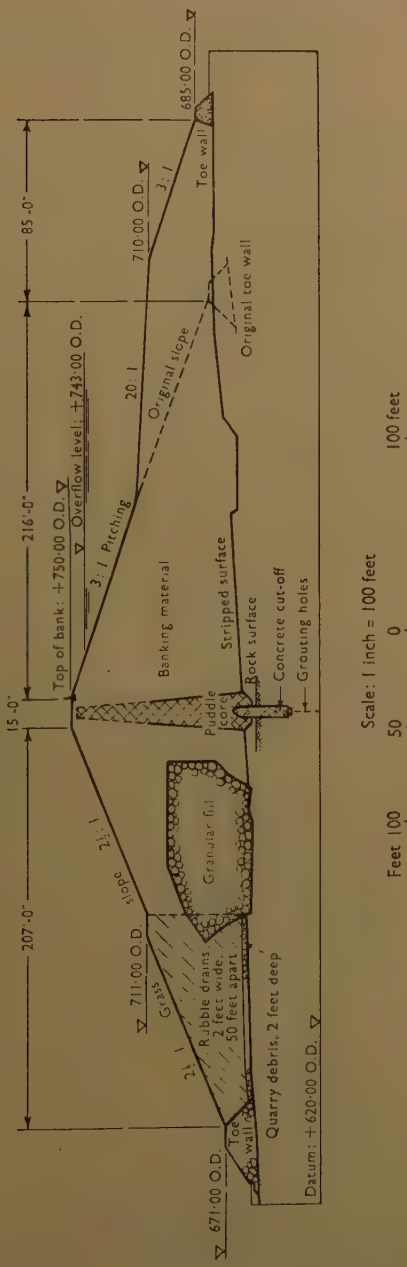


Fig. 2

CROSS-SECTION OF EMBANKMENT

ends of the dam. About 2,900 tons of cement were injected at an average intensity of 57·3 lb. of cement per square foot, calculated over the area below the bottom of the cut-off wall (as shown hatched in *Fig. 5*). It

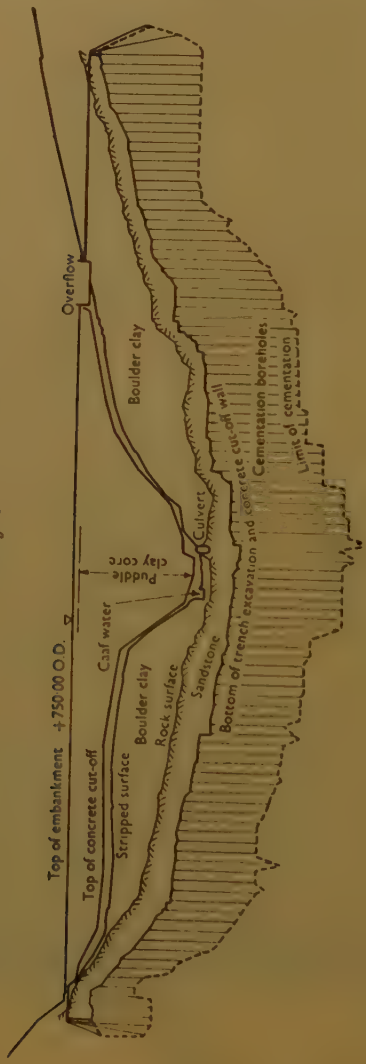


Fig. 5

LONGITUDINAL SECTION OF CUT-OFF

is of interest to compare the injection required in this sandstone formation with that for the very different formation, consisting of volcanic ash with whinstone intrusions, which exists at Muirhead. The depth of cementation bores was generally about 10 feet greater at Muirhead than at Knockendon,

but the average intensity of cement injected, assessed on the same basis, was 34·8 lb. per square foot.

Comparison of Designs for Knockendon and Muirhead Dams

Apart from the different rock formation, the conditions on the Muirhead and Knockendon sites were similar. Both dams were founded on boulder clay and this material on the respective sites was used to form the earth embankments. Both dams as originally designed were of the same maximum height—90 feet—but the cross-section of the valley at Knockendon was less regular, so that the higher part of the dam extended over a much shorter length. The dams were of very similar cross-section, although the top width of the Muirhead dam was 17 feet 6 inches as compared with 15 feet at Knockendon and, since samples from the Muirhead trial pits had suggested that the material available there for forming the embankment would be rather more clayey, the downstream slope below the berm was flattened to 3 to 1. Otherwise, there was no practical difference affecting the respective stability of the two designs.

Movement of the Muirhead Dam and Remedial Measures

Formation of the Muirhead dam proceeded rapidly until it reached a height of about 70 feet, when movement of the embankment was observed. The toe walls of the dam remained stationary but there was a displacement of the earthwork practically in a horizontal direction, the extent of displacement varying in almost direct proportion to the height of the embankment. After an exhaustive investigation, it was concluded that a deep-seated slide of the rotational type was in progress and remedial measures were adopted which were effective in stabilizing the embankment. The height of the dam was limited to about 70 feet. The upstream slope of the dam was stabilized by forming a substantial berm and the downstream slope by excavating material from the top of the embankment to relieve the overburden.

The experience at Muirhead led to a change in the design of the Knockendon dam, which was constructed to its full intended height of 90 feet.

Knockendon Investigations

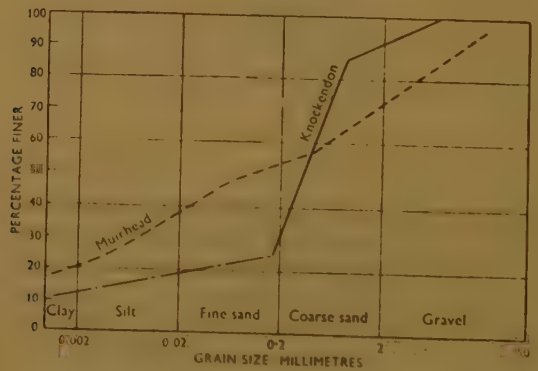
When movement of the Muirhead embankment occurred, it was decided to carry out a soil mechanics investigation at Knockendon and to consider whether or not any modification in the design would be advisable. The results obtained were compared with corresponding tests at Muirhead, where the embankment at that time had for all practical purposes a factor of safety of unity. At Knockendon, the cut-off works below ground, the river diversion culvert and outlet works, and the rubble

toe-walls of the embankment had then been completed. Earthwork in the gully had been raised to a height of about 20 feet above formation level.

The mechanical analysis of the material used for forming the Knockendon embankment shows that about 70 per cent could be classed as coarse sand and gravel having a grain size exceeding 0·2 millimetres. The analysis is shown graphically in *Fig. 6* and the corresponding line for the Muirhead material is shown as a dotted line for comparison. The percentage of fines was certainly greater in the Muirhead material and thus seemed to confirm the deductions made at an early stage from inspection of the trial pit excavations.

Unconfined compression tests of the material already placed in the

Fig. 6.

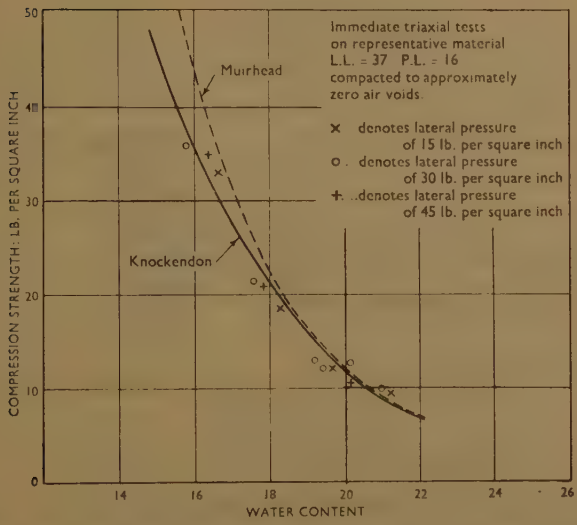


Mechanical Analysis of Banking Material

embankment and in borrow pits were made on the site, using a portable compression apparatus,[1] and samples were sealed and sent for triaxial and other laboratory tests. The relationship between compression strength and water content is shown in *Fig. 7* and the corresponding curve for the Muirhead material is indicated by a dotted line. This shows that the Knockendon material had a somewhat lower strength for low moisture content, but the percentage drop in strength with increasing moisture content was rather more favourable than with the Muirhead material. Within the practical range of moisture content for material placed in the embankment, there was little apparent difference between the strengths of the boulder clays at Knockendon and Muirhead. Triaxial tests gave results somewhat higher than the unconfined compression tests on the corresponding samples. Considered in the light of the mechanical analysis,

[1] L. F. Cooling and H. Q. Golder, "A Portable Apparatus for Compression Tests on Clay Soils." *Engineering*, vol. 149, p. 57 (19 Jan. 1940).

Fig. 7

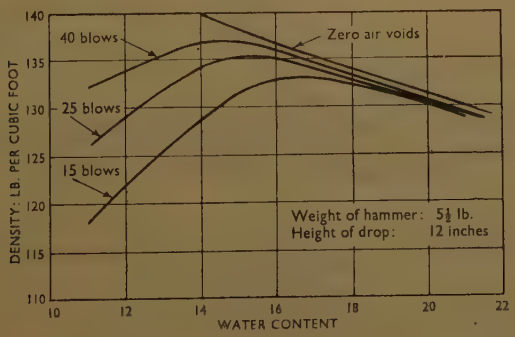


Relation between Compression Strength and Water Content

this suggested that the Knockendon material had a certain frictional as well as cohesive value and in this respect was rather more favourable than the Muirhead boulder clay.

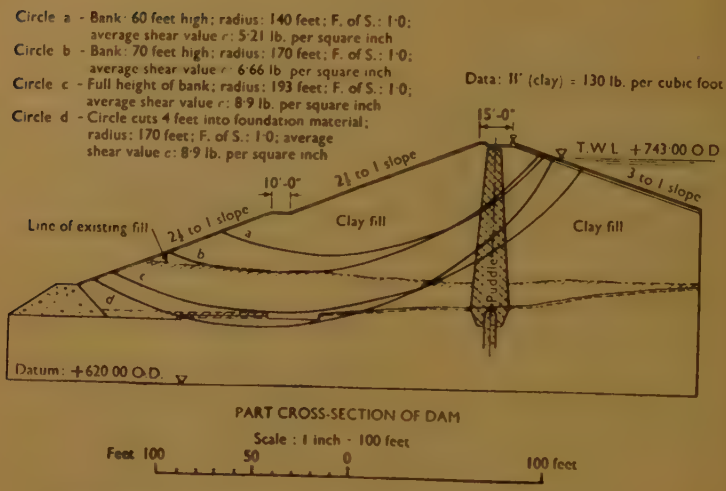
The average liquid limit of the material was 37 per cent and the plastic limit 16 per cent. The results of Proctor compaction tests are shown in *Fig. 8*. With the standard test giving 25 blows from a 5½ lb. hammer dropped a distance of 12 inches, optimum compaction was obtained with a water content of about 15 per cent (of the dry weight), giving a density

Fig. 8



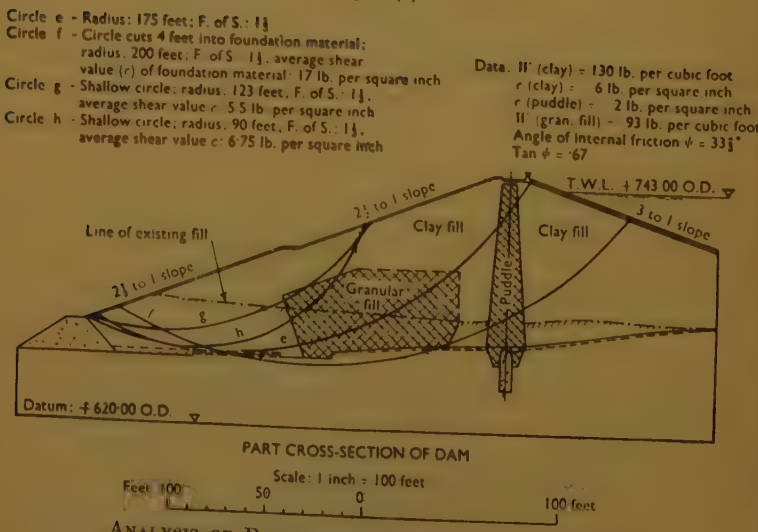
Relation between Density and Water Content. (Proctor Data)

Fig. 9 (a)


Circle a - Bank: 60 feet high; radius: 140 feet; F. of S.: 1·0; average shear value c: 5·21 lb. per square inch
Circle b - Bank: 70 feet high; radius: 170 feet; F. of S.: 1·0; average shear value c: 6·66 lb. per square inch
Circle c - Full height of bank; radius: 193 feet; F. of S.: 1·0; average shear value c: 8·9 lb. per square inch
Circle d - Circle cuts 4 feet into foundation material; radius: 170 feet; F. of S.: 1·0; average shear value c: 8·9 lb. per square inch
Data: W (clay) = 130 lb. per cubic foot
5'-0"
T.W.L. +743·00 O.D
3 to 1 slope
10'-0"
2½ to 1 slope
2½ to 1 slope
Line of existing fill
Clay fill
Clay fill
a
b
c
d
Puddle
Datum: +620·00 O.D.
PART CROSS-SECTION OF DAM
Scale: 1 inch = 100 feet
Feet 100
50
0
100 feet

ANALYSIS OF DOWNSTREAM SLOPE, ORIGINAL DESIGN

Fig. 9 (b)

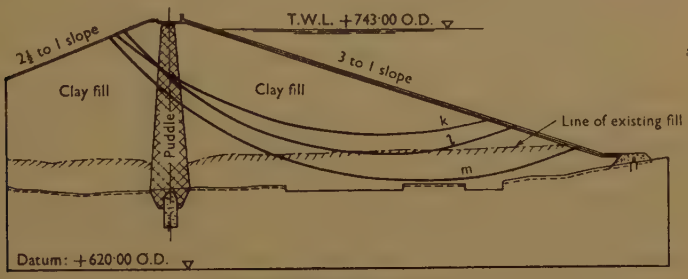

Circle e - Radius: 175 feet; F. of S.: 1½
Circle f - Circle cuts 4 feet into foundation material; radius, 200 feet; F. of S. 1½, average shear value (c) of foundation material: 17 lb. per square inch
Circle g - Shallow circle; radius, 123 feet, F. of S.: 1½, average shear value c: 5·5 lb. per square inch
Circle h - Shallow circle; radius, 90 feet, F. of S.: 1½, average shear value c: 6·75 lb. per square inch
Data. W (clay) = 130 lb. per cubic foot
c (clay) = 6 lb. per square inch
c (puddle) = 2 lb. per square inch
W (gran. fill) = 93 lb. per cubic foot
Angle of internal friction ψ = 33½°
Tan ψ = ·67
T.W.L. +743·00 O.D.
3 to 1 slope
2½ to 1 slope
Line of existing fill
Clay fill
Clay fill
2½ to 1 slope
Granular fill
f
g
h
e
Puddle
Datum: +620·00 O.D.
PART CROSS-SECTION OF DAM
Scale: 1 inch = 100 feet
Feet 100
50
0
100 feet

ANALYSIS OF DOWNSTREAM SLOPE, MODIFIED DESIGN

Fig. 10 (a)

Circle k - Bank 60 feet high; radius: 210 feet; F. of S.: 1·0; average shear value c: 5·17 lb. per square inch
Circle l - Bank 70 feet high; radius: 170 feet; F. of S.: 1·0; average shear value c: 6·28 lb. per square inch
Circle m - Full height of bank; radius: 203 feet; F. of S.: 1·0; average shear value c: 7·89 lb. per square inch

Data: W (clay) = 130 lb. per cubic foot



PART CROSS-SECTION OF DAM

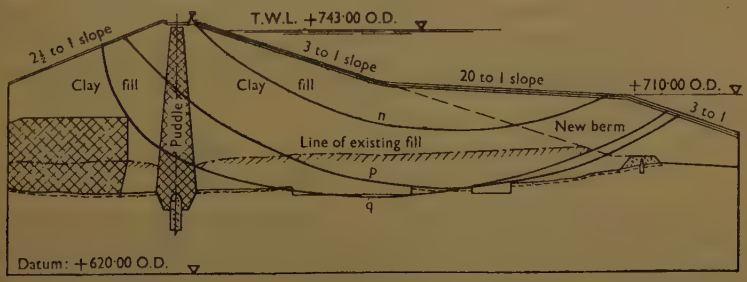
Scale: 1 inch = 100 feet

ANALYSIS OF UPSTREAM SLOPE, ORIGINAL DESIGN

Fig. 10 (b)

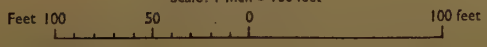
Circle n - Shallow circle; radius: 190 feet; F. of S.: 1½; average shear value c: 6·1 lb. per square inch
Circle p - Radius: 212 feet; F. of S.: 1½; average shear value c (new fill): 7·6 lb. per square inch
Circle q - Double circle; radius: 70/285 feet; F. of S.: 1½; average shear value c (new fill): 7·6 lb. per square inch

Data: W (clay - dry) = 130 lb. per cubic foot
W (clay - saturated) = 135 lb. per cubic foot
c (existing fill) = 6 lb. per square inch
c (puddle) = 2 lb. per square inch



PART CROSS-SECTION OF DAM

Scale: 1 inch = 100 feet



ANALYSIS OF UPSTREAM SLOPE, MODIFIED DESIGN

of 136 lb. per cubic foot (Proctor maximum dry density 118 lb. per cubic foot). Above 15 per cent there was a decrease in density owing to the increasing ratio of water to solid, and below 15 per cent water content the density also decreased because of the difficulty of compacting the dry clay.

Tests on the material already placed in the embankment showed that it had an average water content of 20·1 per cent, which corresponded to a density of 130 lb. per cubic foot and a compression strength of about 12 lb. per square inch or a shear strength of about half this figure. An analysis was made of the embankment as designed, having regard to this ascertained strength of the lower fill. For simplicity in calculations the whole of the clay banking material was assumed to have a density of 130 lb. per cubic foot, discounting the lesser weight of the puddle, although account was taken of its low shear value—2 lb. per square inch.

Shear curves for the downstream side are shown in *Fig. 9 (a)*. Curve a is the critical arc for a bank, 60 feet high, curve b for a bank 70 feet high, and curves c and d for the maximum height of 90 feet. Curve d passes through the foundation material. All these curves are deep shear circles for the respective heights. The most critical result showed that, if calculated for unit factor of safety, an average shear value of 8·9 lb. per square inch was required.

Corresponding curves for the upstream side of the embankment are shown in *Fig. 10 (a)*. Again the deep shear circles were critical and indicated that an average shear strength of about 7·9 lb. per square inch was required, calculated on unit factor of safety.

These values, both downstream and upstream, exceeded the strength of the fill already placed, through which the greater length of the critical shear circles passed. While some improvement in compaction might be expected as the embankment rose out of the limited confines of the gully, this could not have compensated for the limited strength of the lower fill, and the conclusion was reached that appropriate modifications would have to be made in the design of the dam to ensure stability. It was decided that a minimum factor of safety of 1·33 should be obtained and this involved strengthening that part of the embankment which exceeded 60 feet in height.

Modified Design of Embankment

Since the overflow channel, tail-bay, and gauge basin had already been built, any strengthening of the downstream side of the dam by means of a berm at the toe of the slope would have entailed serious and costly alterations, and a solution had to be found which would not affect the downstream profile as originally designed. It was finally decided to excavate part of the existing fill and to replace this with granular material and so strengthen the shear path of the deeper circles. Rock procured on the

site would have served to form the granular hearting, but in view of the time that would have been required to quarry it and the cost involved, it was decided to import slag which was available in bings at Kilwinning, about 8 miles distant. It was ascertained by tests that this material weighed 93 lb. per cubic foot and had an angle of internal friction (ϕ) of $33\frac{2}{3}$ degrees.

The modified design and analysis of the downstream half of the dam is shown in *Fig. 9* (*b*). The shear circle analysis proved that the deep circles were no longer the criteria, although it will be noted that circle f passed through the foundation material and required there a shear value of 17 lb. per square inch. This was satisfied by the strength of the boulder clay which, in its natural state, had a moisture content of about 16 per cent, corresponding to a compression strength of 35 lb. per square inch. The most critical circle was the one designated h in the figure, which required an average shear value of $6\frac{3}{4}$ lb. per square inch in the embankment.

The depth from the surface slope of the embankment to the top surface of the granular fill was determined, taking into consideration the strength of this frictional material relative to the cohesive strength of the boulder clay. The weight of overburden of about 14 feet depth of boulder clay was sufficient to develop the frictional value of the granular material to give a shear strength equivalent to the cohesive strength of the clay.

Various means were investigated for stabilizing the upstream half of the dam. The possibility of removing the lower fill and replacing it with better compacted material was considered but, in view of prevailing weather conditions at the site and the limited operational space in the gully, it was thought to be very doubtful if this measure would give any improvement in strength. The procedure which had been decided upon for the downstream side was examined, but was ruled out because of the adverse effect of the waterlogged fill with reservoir draw-down. It was finally decided to lengthen the path of the critical shear circles in the upstream half by forming a berm in boulder clay at the upstream toe, as is shown in *Fig. 10* (*b*). The decision to use boulder clay in preference to rubble was made solely on economic grounds.

Interference with works already constructed, which was a governing factor on the downstream side, was not such a serious matter upstream. The existing forebay was boxed in to form an extension of the culvert and continued out to the new upstream toe, where a new forebay was constructed. The existing toe wall was, of course, incorporated in the berm and a new rubble toe constructed to conform with the modified design.

In contrast to the downstream side, the deep shear circles continued to be the criteria upstream. Curves p (single circle) and q (double circle), were equally critical, since they required an average shear strength in the embankment of 7·6 lb. per square inch in the fill still to be placed. With the embankment rising from the more confined width of the gully, it was anticipated that this requirement could be achieved.

Another factor considered in the stability analysis was the active pressure on the shoulders of the embankment from the puddle clay core. The density of the puddle clay in situ was about 126 lb. per cubic foot and the equivalent fluid weight, calculated according to Bell's formula, was about 109 lb. per cubic foot. If the effect of this was realized in practice, then the average shear stress in a horizontal plane near the surface of the lower fill of the upstream half of the embankment would be about 6 lb. per square inch and the factor of safety of the dam would be little more than unity (1·08).

The Author is very doubtful if such a condition of puddle pressure is developed in practice and in this connexion there seems to be scope for further investigation. Having regard to the narrow width of a puddle core relative to its height, it may be that the problem is somewhat analogous to pressure in a long continuous bin. A modification of the Bell formula, taking account of the cohesive resistance between the puddle clay and the banking which supports it, would reduce the equivalent fluid pressure in the Knockendon case from 109 lb. per cubic foot to about 65 lb. per cubic foot and the factor of safety of the embankment, computed accordingly, would be increased to 1·8. This may be little more than a tentative line of approach to the problem, but the Author is of opinion that the result, as compared with calculations based on the normal Bell theory, is more in accord with actual conditions. It was considered that the effect of puddle pressure was certainly less than was indicated by the normal application of the Bell formula and that, on this hypothesis, the factor of safety would not be less than the 1·33 accepted as the minimum requirement. Consequently, any increase in the modified cross-section of the embankment, as derived from shear-circle analyses, was not warranted. Nevertheless, particular care was taken during construction to keep the water content of the puddle clay down to the minimum and, as the work progressed, the method of forming a watertight core was altered.

The cross-section of the embankment in accordance with the modified design is shown in *Fig. 2*.

Construction Procedure

The boulder clay excavated from the borrow pits was transported in dumpers to the embankment, where it was spread and consolidated by bulldozers. When the bank had been formed to the top of the gully, thus affording more operating length, the dumpers were supplemented by scrapers and Euclids. This additional equipment was dispensed with as the bank approached its full height and the operating space narrowed. Plant arrangements in general were not altered on account of the soil mechanics investigation or the modified design of the dam.

According to the specification, the embankment material was to be deposited, spread, and compacted in layers not exceeding 12 inches deep,

the layers being inclined from the outer slopes towards the puddle core. In the light of experience at Muirhead, this procedure was modified so that the operating surface drained outwards. Strict precautions were taken, by cutting grips or by other means, to ensure that no water could lie on the surface, and earthwork operations were suspended in wet weather when it was feared that the conditions might adversely affected the water content of the compacted material. Regular tests were carried out on the material in the borrow pits and in place on the embankment to ensure that strength requirements were being achieved and, so far as possible, the more granular materials were selected from the borrow pits.

Although the granular fill in the downstream half of the dam connected with the layer of quarry debris provided for drainage, and also intercepted the vertical rubble drains, the additional precaution was taken of drilling holes through the wall of the culvert, just above the invert, to afford relief for any water which might tend to accumulate in the hearting.

The very marked drop in the strength of the boulder clay with a small percentage increase in water content will be noted from the graph in *Fig. 7*. A relatively high water-content was, however, required to produce properly puddled clay and consequently the puddle-clay core had a very low shear strength (2 lb. per square inch). Furthermore, not only did the uncertain factor of fluid pressure from the puddle core have to be borne in mind, but also the plasticity of the puddle restricted the use of consolidating equipment in the zones of the embankment adjacent to the core, so that the strength of the material in these zones was lower than elsewhere. Since the whole embankment was formed of boulder clay, which is relatively impervious, it was suggested that the puddle core might be dispensed with altogether. The Author was not altogether favourable to this course because water in the sub-strata extends to the cut-off. As the concrete cut-off was poured, this underground water rose with it ; this was, in fact, evidence that the cut-off was performing its function. At Muirhead some leakage, which was rectified by pressure grouting, occurred at the construction joint in the culvert immediately upstream from the cut-off, at a very early stage in the filling of the reservoir. There seems to be no doubt that water is present at the base of the embankment right to the centre, which would suggest that, if the puddle core were dispensed with, the downstream half of the embankment would have to be relied upon for watertightness, a condition which could not have been accepted at Knockendon, taking into consideration the granular fill on the downstream side.

In order to improve compaction in the central zone of the embankment, however, a departure was made from orthodox procedure in forming a puddle core, when the embankment had reached approximately half its full height. Souring of the puddle, before placing, was dispensed with. The boulder clay was spread in layers across the whole width of the embankment and was watered cautiously along the line of the puddle core and over a corresponding width. By this procedure plant could traverse

the central zone and thus achieve uniform compaction throughout. Movement of the consolidating plant and transport across the watered zone had sufficient puddling effect on the clay there to ensure water-tightness.

Subsequent Investigation

Trial pits and the soil mechanics investigation at Muirhead had revealed that the lower fill of the Muirhead embankment had deteriorated to a very marked degree from its strength at the time it was placed. Although a careful check had been kept on the strength of the material placed in the Knockendon embankment, it was deemed advisable, when the level of the top of the upstream berm was reached, to sink bores into the lower fill and to carry out a general check on the strength and stability of the dam.

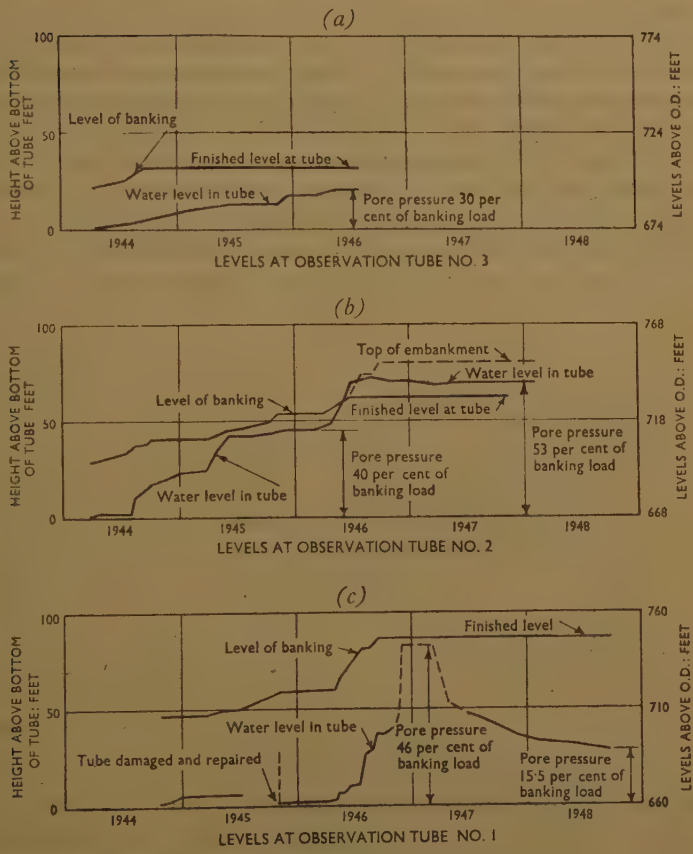
Ten 6-inch-diameter bores were sunk, not without difficulty because of the stones and boulders in the compacted fill. The investigation was confined to the highest section of the upstream half of the embankment, there being no call for further study on the downstream side, which was largely dependent on the frictional value of the granular fill.

Samples for testing were taken at frequent intervals in each of the boreholes. The results indicated that the strength of the lower fill had been maintained at approximately 6 lb. per square inch in shear and that the overall strength of the material placed was in reasonable agreement with the factor of safety of 1·33 assumed in the modified design.

Observations were made on the water level in the boreholes during the boring operations. In two of the boreholes water rose above ground level when the tubes were left projecting overnight, thus indicating that the water pressure in the pores of the bank material was greater than the static head of water above it. This suggested that the material had not consolidated under the overburden of bank material placed and it was decided to drive pore-pressure tubes so that changes in pore pressure could be observed and noted. Four 3-inch-diameter tubes, fitted with pointed metal caps at the bottom and perforated with ¼-inch-diameter holes in the bottom length of 12 to 18 inches, were driven into the embankment. The positions of these tubes are shown on the plan in *Fig. 1.*

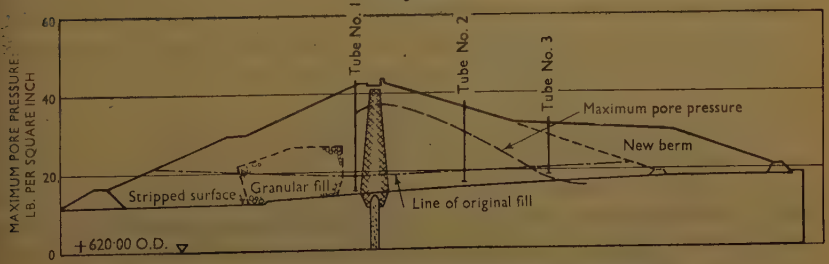
Tubes 1, 2 and 3, which were on the line of the deepest cross-section of the embankment, penetrated to the lower fill. Observations from these are shown graphically in *Figs 11.* The level of the embankment was plotted as work proceeded and also the corresponding actual water levels in the tubes. It will be noted that in tube No. 2 the water level rose above the finished level of the embankment at the tube, which may have been partly due to the greater height of the embankment beyond the tube. The maximum pore pressure in lb. per square inch is plotted diagrammatically on a cross-section of the embankment in *Fig. 12.* (It should be noted that it is the intensity of pressure that is indicated and not the actual

Figs 11


(a)
HEIGHT ABOVE BOTTOM OF TUBE: FEET
LEVELS ABOVE O.D.: FEET
Level of banking
Finished level at tube
Water level in tube
Pore pressure 30 per cent of banking load
LEVELS AT OBSERVATION TUBE NO. 3
(b)
Top of embankment
Water level in tube
Level of banking
Finished level at tube
Pore pressure 53 per cent of banking load
Pore pressure 40 per cent of banking load
Water level in tube
LEVELS AT OBSERVATION TUBE NO. 2
(c)
Finished level
Level of banking
Water level in tube
Pore pressure 46 per cent of banking load
Tube damaged and repaired
Pore pressure 15·5 per cent of banking load
LEVELS AT OBSERVATION TUBE NO. 1

OBSERVATIONS OF PORE PRESSURES IN EMBANKMENT
(NOTE.—Weight of banking : 130 lb. per cubic foot.)

Fig. 12

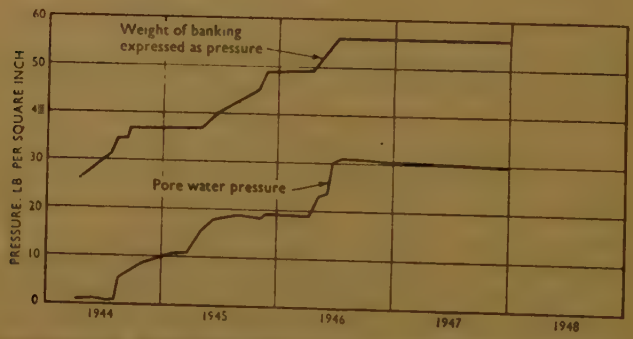


DISTRIBUTION OF MAXIMUM PORE-WATER PRESSURE

water level, which approached or rose above the finished bank level as already mentioned.)

The pore-water-pressure observations enabled a continuous check to be made as to whether or not the embankment material was consolidating, and also provided data to verify the shear strength of the soil by equilibrium shear-strength tests. The pore pressure could be expected to rise as the overburden of banking material was placed in successive layers, but should drop as the embankment gains strength by consolidation. In *Fig. 13* the intensity of pore-water pressure and the weight of banking expressed as pressure is plotted for observation tube No. 2. It will be observed that the rise in pressure corresponds approximately to the pressure

Fig. 13



Comparison of Pore-Water Pressures with Weight of Banking (Observation Tube No. 2)

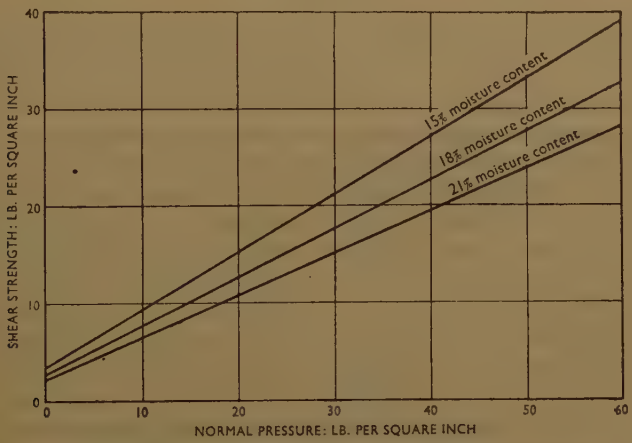
resulting from overburden, but that from May 1946, when the embankment at the tube had been placed to its full height, a gradual though slight fall in the pressure occurred. Continued observations on tubes Nos 2 and 3 ceased when the reservoir was filled, but observations on tube No. 1, placed immediately downstream of the puddle core, were continued until the end of 1948. By then the pore pressure had dropped from a maximum of 46 per cent to 15·5 per cent. A recent check on tube No. 1 (March 1951) showed that the tube is quite dry. However, as this tube is not far removed from the granular fill, which will relieve water from the embankment, it may not be typical of the general condition.

Deductions from Pore-Pressure Observations

The effective pressure at the bottom of the pore-water tube is the total pressure caused by the weight of banking (130 lb. per cubic foot) less the uplift caused by pore-water pressure. The effective pressure at tube No. 2 was calculated to be 26·4 lb. per square inch and at tube No. 3, 27 lb. per

square inch. It was estimated that the corresponding pressures at the top of the initial fill forming the embankment would be about 15·25 and 21 lb. per square inch respectively. The lines of equilibrium shear plotted in *Fig. 14* were derived from the standard Proctor compaction tests and are plotted for initial moisture contents of 15, 18, and 21 per cent. The average moisture content of the lower fill at the time of the later investigation was 18 per cent as compared with 20·1 per cent at the time of the first investigation. It was considered unlikely that the initial fill was compacted to a degree corresponding with the standard Proctor technique. If, to compensate for this, the initial moisture content was taken at, say, 21 per cent, then the shear strength at tube No. 2 would be 9 lb. per square inch

Fig. 14



Equilibrium Shear Strength of Original Fill

and at tube No. 3, 11 lb. per square inch. Assuming that the lower of these values applied, a considerable increase in strength of the lower fill was indicated as compared with the value adopted in the modified design (6 lb. per square inch). The calculations based on the pore-pressure results and the equilibrium shear tests suggested that the factor of safety of the embankment was approximately 2, indicating an increase of about 50 per cent as compared with the data adopted for design.

It is appreciated that there are important uncertainties concerning these results, particularly the initial moisture content and degree of compaction of the lower fill; also, the pore pressure points were limited in number and may not have been representative of the embankment as a whole. The percolation rate from a clay embankment is normally so slow that pore pressures greater than those recorded from water levels in the tubes may have been present in the embankment at the time of observation. It will be noted from *Figs 11* that the highest pore pressure recorded

was 53 per cent of the overburden (tube No. 2). The Author understands that the practice adopted tentatively at that time (1946) by the United States Bureau of Reclamation was to use a pore pressure of two-thirds of the load as a criterion for design. It is interesting to observe that, if this criterion were applied to the Knockendon embankment, the shear strength results deduced in relation to pore pressure would be practically in agreement with the value actually adopted for the modified design. Apparatus much more elaborate than the elementary pore-pressure tubes used at Knockendon is in use in the United States and elsewhere abroad, and the important results obtained during the construction of earth embankments such as the one at Knockendon suggest that more serious attention should be given to this aspect than has hitherto been customary in Great Britain.

Influence of Construction Period on Design of Earth Dams

Reference has been made earlier to the prolonged period of construction of Knockendon dam, dictated by circumstances prevailing at the time. When the design was modified, there was no reason to anticipate that progress would be other than normal and, in the Author's opinion, the design was adequate to ensure stability both during construction and subsequently. However, there can be no doubt that the factor of safety was increased by the enforced delay in construction. If an embankment is formed too rapidly, the increasing overburden which develops as succeeding layers of earthwork are placed may increase the pore-water pressure at a greater rate than it can dissipate and the stability of the embankment may, at least temporarily, be critical. No pore pressure observations were taken at Muirhead, but it seems possible that just such a condition developed sufficiently to reduce the factor of safety to unity. It might therefore be inferred that, where an embankment has to be formed of material such as boulder clay, it would be prudent to place some limitation on the rate of construction afforded by modern muck-shifting plant. But there are other factors to be taken into account.

In practice it is difficult to keep the extensive surface of an embankment under construction free of water and, where water-retentive materials have to be used, it is necessary, after each rained-off period, to remove the softened surface material from the earthwork before any additional banking can be placed. If this work is not done very thoroughly, softened layers of water-bearing material will be formed in the embankment to the detriment of its stability. From this aspect it is obviously desirable to make as much progress as possible during seasons which afford better opportunity for more effective compaction and consequently less scope for water being absorbed into the deposited material. It is significant that the rapidly placed upper fill of Muirhead dam, deposited mainly in the summer season, was more homogeneous and of greater strength than the lower fill

which had been placed slowly but had suffered from exposure and the adverse effect of winter snows.

There are, therefore, arguments for and against rapid construction. It is, however, incumbent on engineers to take advantage of the facilities which the latest type of plant affords and to make due allowance for this when designing—for example, by a more conservative assumption of the pore-water pressure likely to be developed than would be necessary if a slower programme of construction was contemplated. As there is usually an urgent necessity to provide either water or power to consumers and also the capital investment is such that an early return is imperative, it would rarely be a practicable proposition to extend the construction period sufficiently to gain material advantage, having regard to the slow rate at which pore-water pressure is dissipated in a clay embankment. This, in effect, means that the gain in strength with time pertaining to slow construction must largely be discounted. It follows, therefore, that the urge for speed in the completion of works may so affect the design as to reflect seriously on its economics. For example, the cross-section of an earth embankment might have to be so increased that on the score of cost an entirely different form of construction, such as a concrete dam, would be warranted. Also, where the materials available on the site for the construction of an earth dam are non-frictional, either a limit may have to be placed on the safe height to which a dam may be built, having regard to the desired construction period, or again some radically different form of construction may have to be adopted.

Acknowledgements

Soil mechanics is a very junior science and was only in its infancy in Great Britain when the Knockendon and Muirhead projects were started. The Author wishes gratefully to acknowledge the assistance rendered by the Department of Scientific and Industrial Research in connexion with the initial observations and by Soil Mechanics Ltd, who undertook the subsequent investigation. The advice obtained from these sources was most valuable to the engineers and of fundamental importance to the successful completion of the works.

The Paper is accompanied by two photographs, one map, and twelve sheets of drawings, from some of which the half-tone page plates and the Figures in the text have been prepared.

Paper No. 5867

"The Skylon"

by

Felix James Samuely, B.Sc.(Eng.), A.M.I.C.E.,
and Percy James Alfred Ward, A.M.I.E.E.

(Ordered by the Council to be published with written discussion)†

SYNOPSIS

The Paper describes the architectural aspects, the design, the fabrication, and the erection of the Vertical Feature—later named "The Skylon"—at the South Bank Exhibition, 1951.

The architectural form of the structure, in relation to the general characteristics of the site, is discussed, and a detailed description of the fabrication of the principal parts, and of the system of erection adopted, is given.

The magnitude, distribution, and nature of application of loading were, naturally, given very careful attention during the preliminary design stages. Since the structure is pre-stressed steelwork, of which very little experience was available, many of the problems encountered had to be solved for the first time, and the results were later checked by wind-tunnel tests on models. Recommendations for wind loading, taken from various sources, are discussed briefly and compared with the results of the wind-tunnel tests.

The stability of the Skylon depends largely upon the pre-stressing of the structure, and this aspect of the design, and the method of pre-stressing, are explained.

A particular feature of the design is the lateral support afforded to the three main struts by the pre-stressed pennant cables passing over their heads; it is shown that in certain circumstances a mast may be stayed in one plane only, and general equations for stability are evolved.

Introduction

Two years before the opening of the South Bank Exhibition, 1951, a competition was held for the design of a "Vertical Feature" which was to be 250 feet high and to cost not more than £15,000. This competition was won by Phillip Powell and Hidalgo Moya, two young architects who had previously won the competition for the Pimlico Flat Development Scheme.

Their scheme consisted of a "Feature" that was not resting on the ground, but was completely suspended in the air, held in position by a number of cables. Three supporting struts were arranged to keep the cradle of cables in position, the cables being attached to the centre and bottom of the Feature, as shown in *Fig. 1* (facing p. 452).

† Correspondence on this Paper should be received at the Institution by the 1st November, 1952, and will be published in Part I of the Proceedings. Contributions should be limited to about 1,200 words.—Sec. I.C.E.

It is remarkable that the architects were able to evolve a design of so decidedly an " engineering " nature without the assistance of an engineer. Only after Messrs Powell and Moya had won the competition and had been instructed to proceed with the detailed design of the Vertical Feature, which was later named " The Skylon," did they appoint Mr F. J. Samuely as their Consulting Engineer. Tenders were invited for the structure and the contract was awarded to British Insulated Callender's Construction Co. Ltd, for preparation of shop drawings, fabrication, and erection. Although time was very limited, owing to the fixed opening date of the Exhibition, the Skylon was completed in good time.

Architectural Aspects

The architectural aim was to design a simple dominant vertical feature, soaring upwards in direct contrast to the complex and horizontal character of the exhibition lying at its foot. This feature, a tall thin pointed body, was to be poised 40 feet above the paving—a heavier-than-air structure suspended in a cradle of steel cables supported on three struts. The struts, less than 70 feet high, were not to stand out prominently from the exhibition buildings. The deliberate illusion was thereby to be created of an unusual structure, divorced from the earth, yet with its design based on simple and practical mechanical principles.

Viewed from a distance, or from across the river, the Feature—shining in the sun by day, illuminated from inside by night and reflected in the river—was to give the appearance of a pointer to the exhibition.

At the same time, it was also very important that the feature should be impressive, not only from a distance, but also from close quarters. It was felt that, on this congested site, a vertical feature solidly resting upon the ground would lose its impressiveness when viewed from near by, however important and grandiose it might appear from a distance ; its solid connexion with the ground might also cut up the fine clear area of paving out of which it would rise. But when it was poised above the ground, the paved area was unbroken and exhibition visitors could walk underneath with dramatic views upwards.

The body was covered with horizontal satin-finished aluminium louvres at 3-inch centres and the lighting was effected by a series of tungsten-filament lamps arranged in groups of three in inverted conical reflectors situated in the centre of the feature, the lamps being in watertight holders. The total power of the lamps was 44·5 kilowatts and the intensity of the lighting was graded throughout the height of the feature—being brightest at the top.

Structural Design

The original design, using aluminium throughout, was abandoned in favour of a steel frame with aluminium cladding, for reasons of economy,

and the extra weight of the steelwork was very useful in helping to stabilize the Feature. Another change from the original design was that the lattice struts were replaced by solid construction (part 2 in Fig. 3, Plate 1). This possibly regrettable change was made because the Festival Authorities considered that the lattice struts would bear too great a resemblance to the supports of the neighbouring Dome of Discovery.

The most difficult structural problem was to avoid setting up the high dynamic forces which could be caused by excessive movement of the structure under load. Under normal circumstances, and with ordinary stresses, considerable movement would occur at the top of the Feature, while the bottom would remain almost at rest. The movement at the top would be between 3 feet and 4 feet either way with a wind velocity of 80 miles per hour. This movement would not appear to be considerable from the ground but it would set up large dynamic forces owing to the constant acceleration and deceleration of the mass, and this, in turn, would have set up additional static forces which would have resulted in the need for very large cables (about 5 inches diameter).

To avoid such unsightly and expensive cables, pre-stressing appeared to be the only answer. Pre-stressing did not reduce the original forces in the cables but it was possible to stabilize the Feature in such a way that the movement at the top was reduced to approximately 9 inches and the dynamic forces, being proportional to the square of the amplitude, were reduced to about one-sixteenth of their original value, and so became negligible.

It is appreciated that a certain amount of pre-stressing is inherent in any structure or mast that is stayed by cables but usually the stresses involved are small by comparison with those under load, and such structures are not ordinarily regarded as pre-stressed. Tension may be induced into a cable by increasing its span ; by shortening its length within a span ; or by transverse loading. When loading is uniformly distributed, such as self-weight or wind pressure, its effect on the cable tension is called the " catenary effect," and this commonly plays havoc with all calculations of redundancy in cable-braced structures.

Pre-stressing, therefore, becomes effective only when it is carried out to a degree that far exceeds the normal tensioning of most stays. Investigation showed that if high-tensile-steel cables were pre-stressed to 100 per cent of the full-load value the catenary effect could be neglected for cables having a horizontal projection of up to 400 feet ; if they were pre-stressed to 50 per cent, a horizontal projection of 280 feet, and to 20 per cent, a projection of 170 feet, and so on. Since the horizontal projection of the cables for the Skylon was only 64 feet with a pre-stress of 50 per cent the catenary effect was neglected.

Pre-stressing of a structural system which includes cables is very similar to the pre-stressing of concrete, but in reverse. Concrete cannot take tension, whereas cables, normally, cannot take compression. After

being pre-stressed, reinforced concrete is capable of taking a certain amount of tension, and cables of taking compression.

Fig. 2 shows this theory in principle, in one plane. By pre-tensioning the cables shown (a and b) to, say, 5 tons a compressive force of 8 tons is set up in the mast (c). If a horizontal force of 6 tons is now applied at the top of the mast, this force is taken entirely by the two stays. The leeward one (b) would be relieved of its tension and would have a final stress of zero, while the stress in the windward stay (a) would be doubled to 10 tons.

Fig. 2

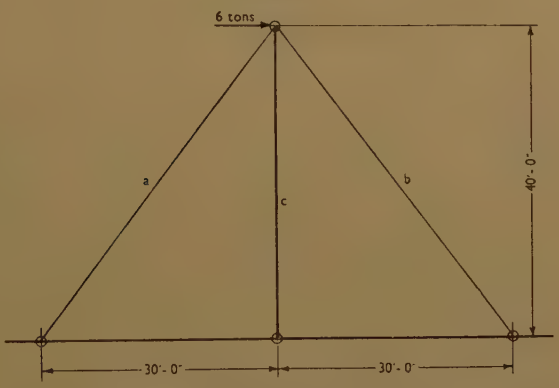


Diagram of Forces to Illustrate the Pre-stressing of Cables

The compression in the mast would remain unaltered. These are the same forces that would occur if the system was not pre-stressed, but the deflexion at the top is very much reduced.

For the Skylon, this principle was applied in space instead of in one plane, with three systems of stays arranged at 120 degrees to each other. It can be seen from Fig. 3, Plate 1, that there are two systems, each consisting of three cables. One set runs from the anchorage points (point 5) beyond the struts up to the centre of the Feature (point 9) and one set from the anchorage points (point 5) over the tops of the struts (point 11) down to the bottom of the Feature (point 7) up to the top of the other struts and down to the corresponding anchorage points. Altogether, there are three cables side by side from each anchorage point to the top of the struts—one from the top of each strut to the centre of the Feature, and two from the top of each strut to the bottom of the Feature.

It can be seen that, by tensioning the cables, an initial compressive force is introduced into the lower half of the Feature. There were two possible methods of producing this tension: (1) by using turnbuckles in the cables; and (2) by jacking up the struts from the bottom so that they pressed against the cables. The latter method was selected as being the

simpler, and because the turnbuckles would have been unsightly. The method of jacking will be described later.

Originally, the top of each strut was to be held by two further stays, in addition to those already described that are connected to the Feature, to hold them in position sideways. During the process of design it was found that the two side cables were, in actual fact, unnecessary because the pre-stressing had the effect of pulling the struts back into their own plane against a laterally applied load. Exact calculation showed that there was a larger factor of safety against buckling than is usual, owing to the pre-stressing. (See Appendix I). This fact might be of value for the design of masts in general, because it shows that, under certain circumstances, masts can be stayed in one plane only, omitting stays in all other directions.

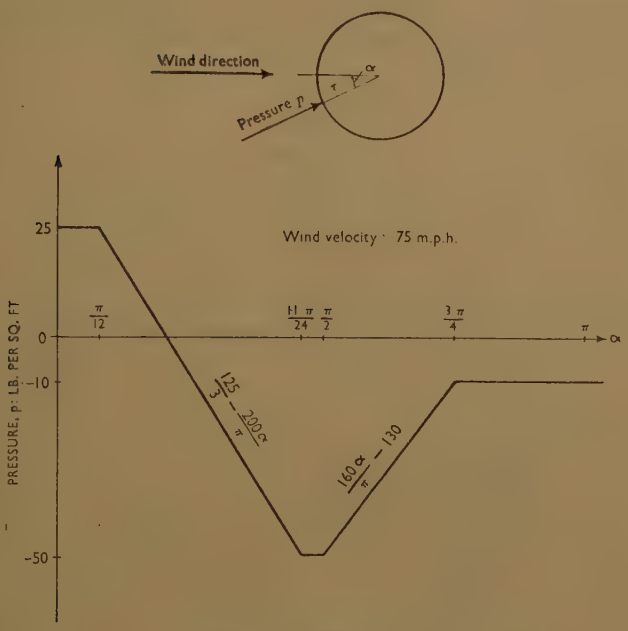
The Skylon was calculated to withstand a wind velocity of 80 miles per hour, which, according to the Meteorological Office of the Air Ministry, is the maximum to be expected in London at a height of 300 feet. For the calculation of the forces in the structure of the Skylon, it was important to assess the distribution of air pressure and suction around the circumference reasonably accurately. Also the fact that the surface was not completely closed in and that the Feature was not cylindrical influenced the wind load. To establish the distribution of wind on the circumference it was decided after long investigation to use the distribution given by Mr Guthlac Wilson (see Appendix II). The curve was modified to give a closer agreement to Flachsbart's publication[1] (see *Figs 4* and *5*).

Wind-tunnel tests showed that it was on the safe side to assume that the Feature was fully closed in. In fact, this appears to be correct for the centre part of the Feature whilst for the ends, which were more open, wind tunnel tests showed that it would have been sufficient to take into account only 85 per cent of the longitudinal section. Furthermore, from the results of previous wind-tunnel tests it had been established that the most dangerous period of oscillation was 0·5 cycle per second, and because of this a factor of 1·8 should be allowed for acceleration and gusts. No additional factor of safety was necessary if the frequency was higher than 2·8 cycles per second. The rate of vibration of the Skylon was calculated to be approximately 1·02 cycles per second. By interpolation it was found that a factor of 1·6 on the load should be used in the final calculation.

Before fabrication was commenced, further wind-tunnel tests were made on a model, designed on this principle, and it was clearly established that, with pre-stressing, a wind velocity of 80 miles per hour with considerable gusts could be resisted without danger. It was also made clear that, without pre-stressing, wind would have caused considerable movement of

[1] O. Flachsbart, "*Windruckmessunger an einem Gasbehalter. Ergebnisse der Aerodynamischen Versuchsanstalt zu Göttingen*" ("Wind-pressure measurements on a gas-holder. Results of Aerodynamics Research Establishment in Göttingen"), 1927, p. 18.

Fig. 4



WIND DISTRIBUTION DIAGRAM
(CIRCUMFERENCE REPRESENTED BY A STRAIGHT LINE)

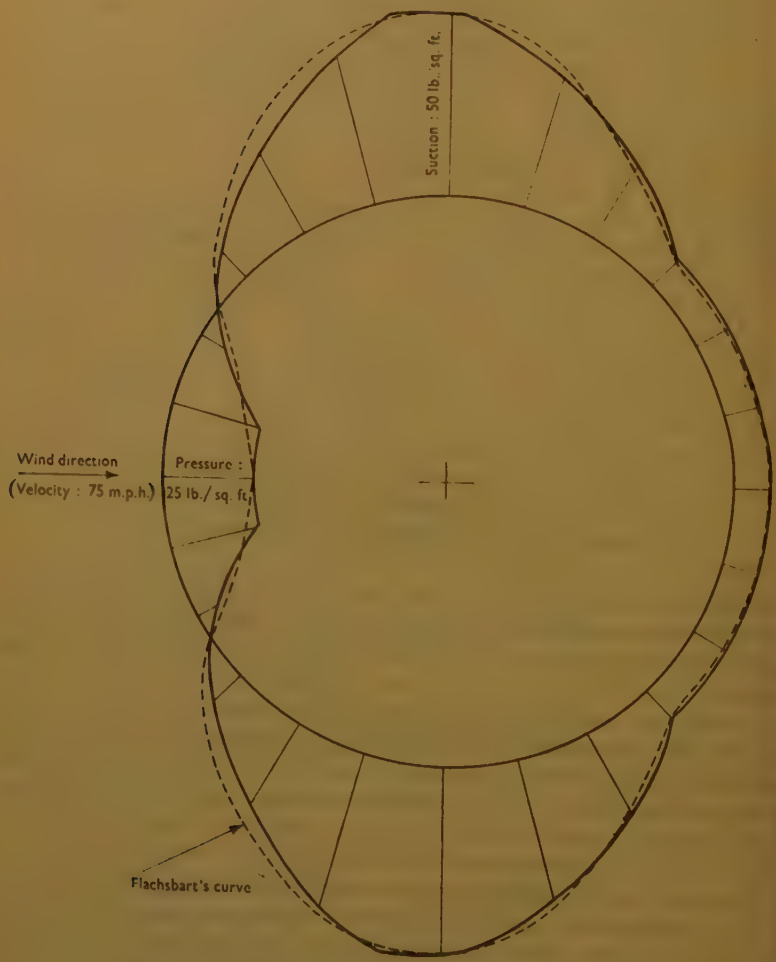
the Skylon and this would have required special precautions. The wind-tunnel tests also confirmed that the theory of omitting the side stays was correct, and no difference in behaviour was apparent after they had been removed.

The Skylon, which is of duodecagonal (twelve-sided) cross-section, is constructed on much the same principle as an airship; that is to say, it has latticed construction in the surface only, covered by skin. There are twelve latticed girders, one for each surface, running from top to bottom of the Feature, shaped so that the Feature tapers to a point at both ends. It has a diameter of 13 feet at the centre.

The connexion between the foundations and the actual Feature was of considerable importance. The struts produce compression forces and the cables produce appreciable tension, the vertical component of which is 146 tons. This tension is reduced or increased by 54 tons for the worst wind pressure, whilst the compression remains almost constant. The transmission of these forces to the foundations would not normally have presented any difficulties, but owing to the fact that the struts were jacked up from the base to effect the pre-stressing, they had to be hinged at the bottom and provided with jacking members or beams.

The base of one strut is shown in *Fig. 6* and consists of a plate girder hinged at one end, the strut itself being fixed in the centre by means of another hinge. With this arrangement, the jacks have to sustain only half the load of the struts.

Fig. 5

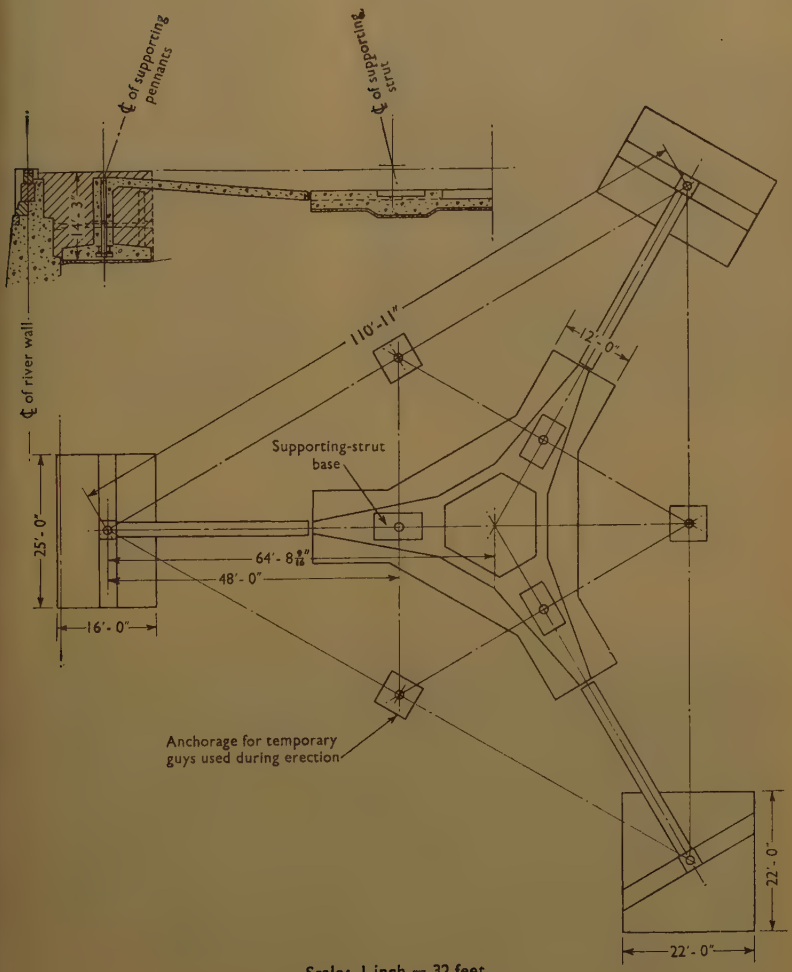


WIND DISTRIBUTION DIAGRAM
(PLOTTED ON CIRCUMFERENCE AS BASE OF ORDINATES)

Although, after jacking, the plate girders were packed in position, the jacks were retained in case the cables slackened and further jacking became necessary. During pre-stressing, the stresses were measured by pressure

gauges on the jacks and stress gauges on the cables. The strain gauges on the cables were left in position, and were used to check the constancy of

Figs 7



Scale: 1 inch = 32 feet

DETAILS OF FOUNDATIONS

the stresses, but up to the time of writing there has been no appreciable loss of tension.

The foundations are star-shaped as shown in *Figs 7*, with blocks at

the end of each arm to provide sufficient weight to counter-balance the vertical component of the tension caused by both pre-stressing and wind load, whilst the arms of the star have mainly to take the horizontal component of the cable tension in compression and are hinged at the ends in order to avoid taking bending stresses.

Fabrication

Supporting Struts

The 70-foot-long struts supporting the Feature (part 2 on Fig. 3, Plate 1) are triangular in cross-section, the corner members each consisting of 6-inch-by-6-inch-by-$\frac{7}{8}$-inch angle with a 4-inch-by-4-inch-by-$\frac{3}{8}$-inch angle nesting into the root, being spaced and reinforced by $\frac{1}{2}$-inch mild-steel plates welded to form tee-sections. On each face a $\frac{1}{4}$-inch thick mild-steel continuous skin plate is fillet-welded to the main angles.

The first problems of fabrication were those of handling and of preventing possible distortion of the heavy components. Each strut was made in three parts—a parallel-sided centre-section, and two tapered end-sections—and these were built up in jigs which could be rotated through 360 degrees so that all welds could be made in the down-hand position.

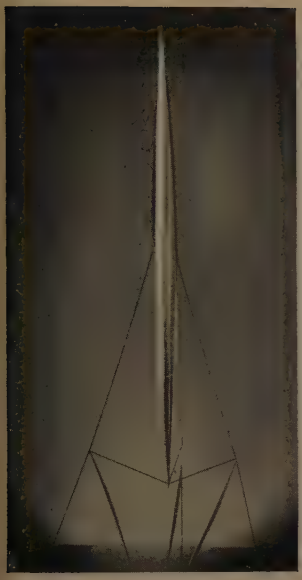
At the head of each strut there is an assembly comprising three steel sheaves which form a bearing for the supporting cables (part 11 on Fig. 3, Plate 1) and at the base there is a unit forming part of a pin-bearing on which the strut is supported (part 6, Fig. 3). The three sections of each strut and these head and base bearings had to be joined together in perfect alignment and some difficulty was experienced with this owing to the awkward size, weight, and section of the parts. Assembly jigs were constructed which positioned the bearings and kept them in alignment during welding and the whole member was lined up and levelled on a concrete road with surveyor's instruments.

The hinged lever at the foot of each strut on which the pin bearing rests is made up of three 12-inch-by-6-inch heavy-section rolled steel joists, placed side by side, with $\frac{1}{2}$-inch-thick web-stiffening plates. The webs were vee-cut and welded to form a slope in the top flanges at one end and, after welding the joists together, a $\frac{5}{8}$-inch-thick plate was welded on to cover the top and bottom faces. To provide greater bearing area at the hinge, a $\frac{1}{2}$-inch-thick plate was welded on each side of each web of the three R.S.Js and the pin-hole for the hinge was bored after the joists had been assembled, to secure accuracy of position.

The Central Feature

Most of the body was built up of rectangular welded panels, 12 feet long, which, when bolted together, form a series of twelve-sided "rings" each with its own diaphragm bracing. On some of the diaphragm bracings, platforms were sited (part 10, Fig. 3, Plate 1), and a spiral ladder was

Fig. 1



ORIGINAL MODEL OF SKYLON

Fig. 6

BASE OF SUPPORTING STRUT

Fig. 8

FOUR LATTICED PANELS, ASSEMBLED READY FOR ERECTION

Fig. 11

"Spider" being Welded

Fig. 12

Bottom Section of Feature and "Spider," after Assembly

Fig. 14

Erection of First Section of Feature

Fig. 15

Tensioning Frame used at Anchorage Points

Fig. 18

THE SKYLON BY DAY

Fig. 19

THE SKYLON BY NIGHT

arranged between these platforms (part 8, Fig. 3) up the centre of the Feature. Each of the panels consists of two side angles, a horizontal angle top and bottom, and an intermediate horizontal member of channel section. They are cross-braced by $\frac{5}{8}$-inch-diameter mild-steel rods, tensioned by special hookbolts at their intersections (see *Fig. 8*).

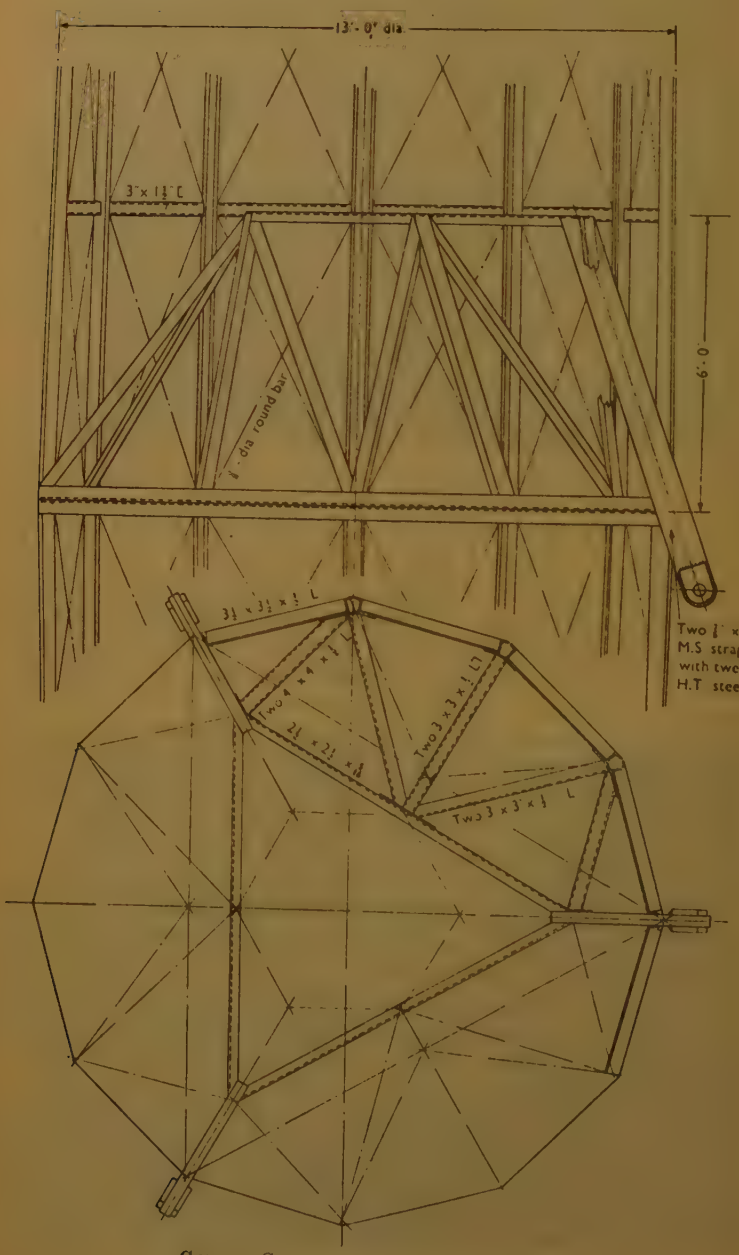
Since the panels were bolted one on top of the other in the structure, with their side angles toe to toe, it was necessary to maintain great accuracy to prevent " growth " during erection. All component members of the panels were completely jigged to ensure a maximum tolerance of 1/64 inch and the panels were welded in assembly jigs capable of lateral adjustment to accommodate the various widths, then removed and checked against a master templet. All mating surfaces were ground off to ensure flush facing, and each " ring " was check-assembled with its diaphragm bracing before being despatched from the works.

One of the most difficult sections to fabricate was that containing the internal stiffening frame at the mid-height of the structure. This framework (see *Figs 9*), distributing loads from the three wind stays (part 3 in Fig. 3, Plate 1), was complicated in that it developed from a triangle at the top to a twelve-sided figure at its junction with the main members of the structure. It was built up mainly of boxed angles, and heavy reinforcement at connexions was added after welding of the main framework, the whole unit being checked for accuracy from time to time. Each of the three connecting plates for the wind-stay cables was split in thickness, the two halves being bolted together during assembly for welding so that, upon completion of the welding process, the whole frame could be broken down into three separate parts to afford easy erection.

At the base of the Central Feature, supporting cables were passed round the lugs of a special spider unit (see *Figs 10*, and part 7 in Fig. 3, Plate 1), the conical part of which was turned from an 18-inch steel billet and bored centrally to receive the 2-inch-diameter tube which runs right up through the centre of the Feature to carry the lights and spiral ladder. The three legs of the spider were cut by oxy-acetylene flame from a 6-inch-thick plate and the grooves for the cables were formed on a lathe but finished by hand to remove sharp edges. Fins, or stiffening fillets, were cut from $2\frac{1}{2}$-inch-thick steel plate and the whole assembly was welded together using high-tensile electrodes (see *Fig. 11*). The finished unit, weighing 26 cwt, was normalized after welding, and tested to $1\frac{1}{2}$ times its working load in such a manner that all the conditions of actual use were reproduced.

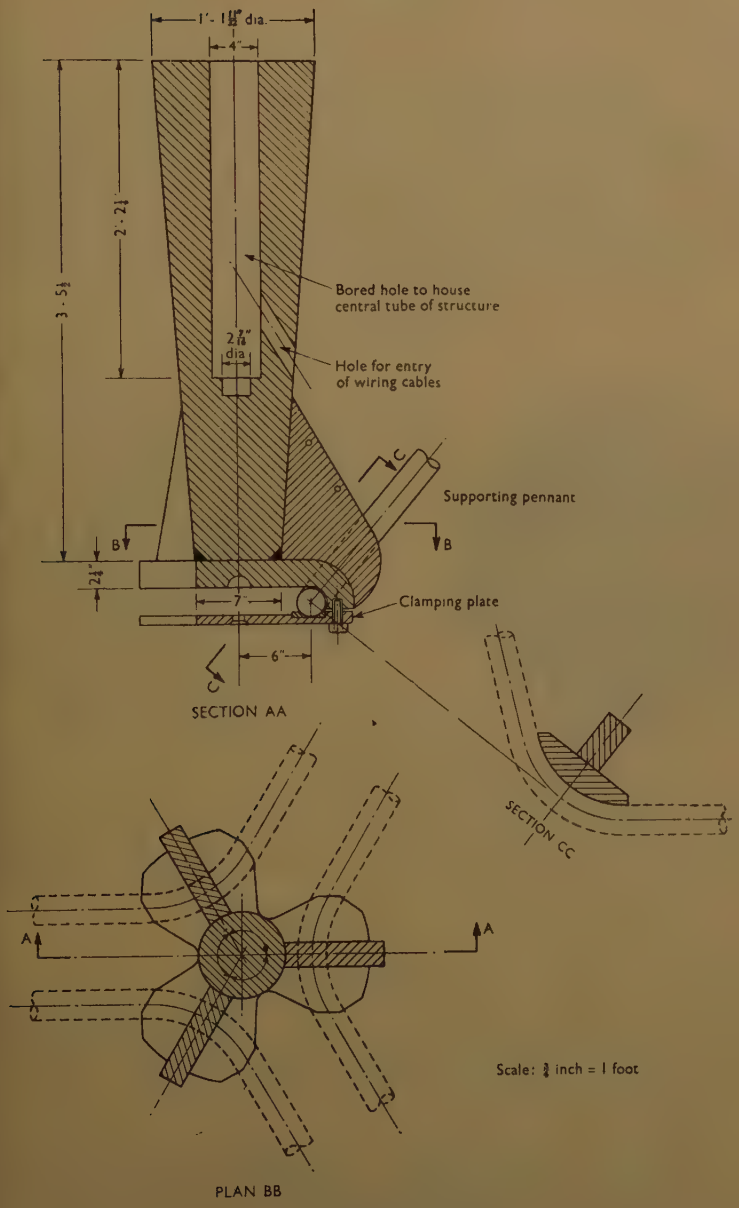
Before joining the spider to the short bottom section of structural steelwork of the Feature, the two parts were pre-heated in a specially prepared hearth and, owing to the mass of the sections, sufficient heat was retained to allow them to be transferred to a welding jig where they were aligned, tacked, and finished with a multi-run weld. The two parts after assembly can be seen in *Fig. 12*. To ensure the reliability of the joint, it

Figs 9


13'-0" dia
3"x 1½" L
1" dia round bar
6'-0"
Two ½" x 8
M.S straps. bolted
with twelve 1" dia
H.T steel bolts
3½ x 3½ x ½ L
Two 4 x 4 x ½ L
2½ x 2½ x ½
Two 3 x 3 x ½ L
Two 3 x 3 x ½ L

CENTRE STIFFENING RING OF FEATURE

Figs 10



"SPIDER" UNIT

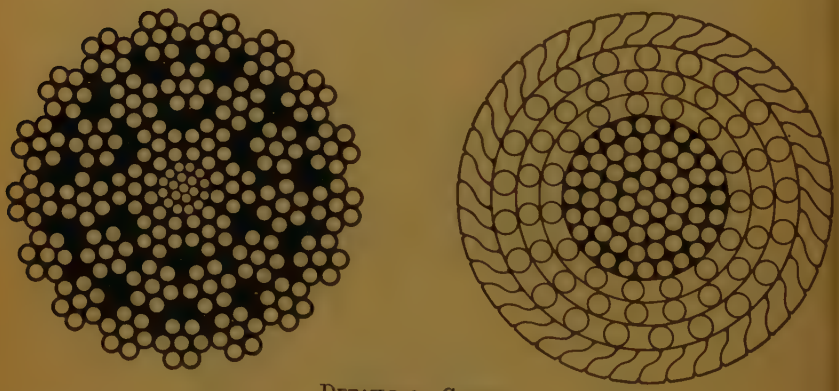
was subjected to a test shear load of 7½ tons. Before transport to site the whole structure was check-assembled at the fabricators' works.

Cables

The three supporting cables which connect to the bottom of the feature (part 4, Fig. 3, Plate 1) are 7½-inch-circumference steel-wire ropes of multi-strand construction with a breaking load of 193 tons (see *Fig. 13* (*a*)), and the three wind-stay cables connecting to the centre of the Feature are 7⅛-inch-circumference locked-coil ropes, constructed with four layers of shaped wire over a spiral core of round wires and having a breaking load of 276 tons (see *Fig. 13* (*b*)). All ropes were constructed from acid steel made by the Siemens-Martin open-hearth process, having an ultimate tensile

Figs 13

(*a*) (*b*)



Details of Cables

strength of 110/120 tons per square inch. Ropes were marked to exact length under maximum working design loads and terminated in forged-steel open-type clevis-sockets.

Erection

A specially designed square column, 45 feet high and of lattice steel construction, was used as falsework to support the central feature of the Skylon during erection. The column, which was supported at the head by four ground stays, was raised into position using a 45-foot-high steel tubular derrick.

The hinged levers at the bases of supporting struts, each weighing 23 cwt, were raised by a winch rope from the head of the falsework and pulled out by tail ropes to their foundations where, after careful levelling, they were grouted into position over pre-set holding-down bolts.

After the sheaves were fixed to the head of each strut, the struts were raised into position by a rig comprising two 30-foot derricks with lifting tackle fixed at a distance of 20 feet from the head and 6 feet from the bottom of the strut. Additional lifting and control tackle was rigged from the falsework to the head of the strut. The base was first landed on its pin bearing and then the strut was raised into position.

To lift the one-piece bottom section of the central feature on to its supporting falsework, two of the struts were luffed inwards to act as derricks, as shown in *Fig. 14*. A 45-foot steel tubular derrick was used for further assembly of the central feature and was lifted through the door opening in the bottom section, and seated inside on the steelwork; the derrick's four head-restraining guys were anchored at ground level.

The individual braced panels of the structure were assembled on the ground into sections of four panels each (see *Fig. 8*), three such sections comprising one complete framed "ring" of the structure. The sections, ranging in height from 12 feet to 18 feet and in weight from 12 cwt to 15 cwt, were raised separately using a power winch and single line, the lifts being controlled by tail ropes to keep the sections clear of the structure. At intervals of 24 feet to 30 feet of height, as erection proceeded, the derrick pole was lifted to a new position and restrained by guys to the steelwork of the structure.

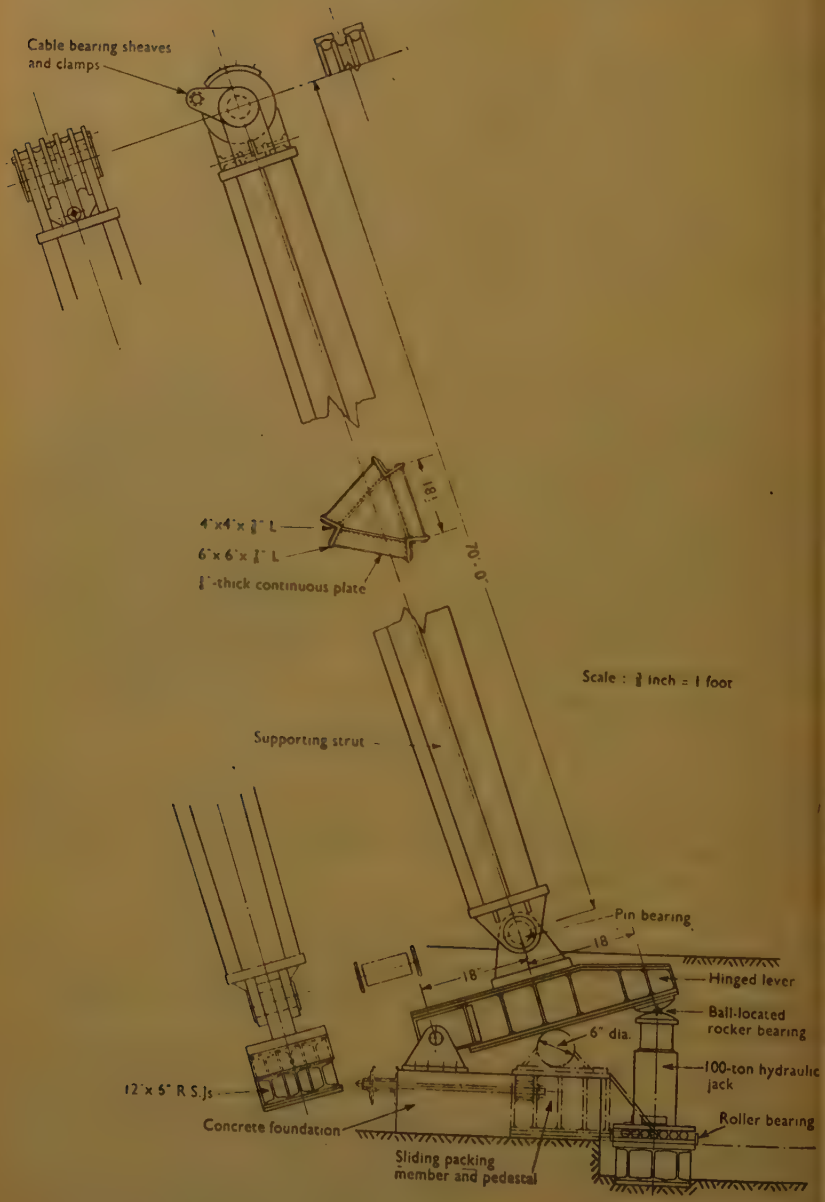
When the Feature had been erected as far as the centre ring, and the attachment plates for the cables had been fitted, further erection of the central feature was suspended while the main cables (wind stays and supporting pennants) were connected.

The supporting pennants were lifted, one at a time, each rope being slung from a point 6 feet either side of its centre length. It was forced into position around a lug on the spider and held by temporary wedge packers driven between the rope and the head of the erection column. The tails of the rope were then raised to the heads of two adjacent supporting struts where they were passed around outer sheaves and, for the time being, allowed to hang freely.

Wind stays were then lifted, sufficient slack being allowed at the top ends for fixing clevis terminations to connecting plates on the structure. The lower ends were lifted out over the centre sheaves on supporting struts to hang with the tails of supporting ropes ready for anchorage at ground level.

The total force required to land the three ropes at each anchorage was expected to be of the order of 15 tons, and to ensure an easy entry of the single push-fit pin connecting all three clevises to their respective anchor plates a special tensioning frame and rig, shown in *Fig. 15*, was used. It was thought that this operation would be the most difficult part of the erection but, although the actual landing tension was approximately 25 tons, the frame held all nine plate and clevis connecting holes in perfect

Figs 16



DETAILS OF JACKING ARRANGEMENT

alignment and no difficulty was experienced in driving home the anchor pins.

When the wind stay and supporting ropes had been completely rigged, the next operation was to induce further tension in them by forcing the three struts upward. By this means, first the supporting ropes were tensioned until they lifted the central feature clear from its falsework and then, of course, further lifting caused the wind stays to tighten.

Jacking arrangements to lever up the supporting struts are shown in *Figs 16*. The jacks and hydraulic pumps had a capacity of 100 tons and the rams had a clear lift of 12 inches. Lifting forces were indicated on pressure gauges calibrated in tons and, when final adjustments were made, the forces were checked on a Macklow-Smith self-contained hydraulic capsule gauge which was inserted beneath each jack in turn.

Jacks were mounted on roller bearings so that they could move freely inwards as the angle of the hinged levers increased. As the jacks were operated, round-sectioned packing members, spanning between supporting pedestals, were moved by screwed tension rods to bear under the hinged levers, so that if a jack failed the load would be held. These packing members also acted as permanent supports with the jacks removed. As a single throw of the jacks was not sufficient to provide the full lift, small pre-cast concrete packing slabs, seated on asphalt, were introduced under the jacks after the first half of the lifting operation had been carried out. These packing slabs were made wedge-shaped, thus inclining the jacks so that the new line of thrust was normal to the slope of the hinged levers.

The curve relating force on the jacks to slope of the hinged levers for the required axial force in supporting struts is shown in *Fig. 17*, and Table 1 shows the total forces in the members.

TABLE 1

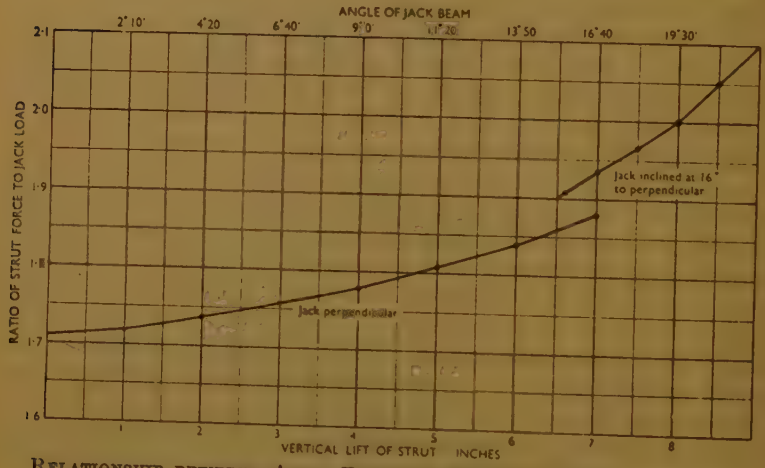
Member	Load : tons			
	Pre-stress	Dead	Wind	Total
A	55	—	53·2	108·2
B	98·9	17·7	3·9	120·5
C	153·9	17·7	57·1	228·7
P	−154	−26·8	−6·1	−186·9
F	−156	−28	—	−184

After pre-stressing, erection of the central feature continued, using the method previously described, until only the topmost section remained to be fitted. To erect this 18-foot-long one-piece section, the derrick-pole was lifted out of the structure and secured to the outside, head guys being taken to ground level. When the section had been lifted and landed, an erectors' cradle was hoisted from the top of the derrick for the purpose of

fitting an anemometer and wind-direction vane to the summit of the structure.

To hoist the aluminium cladding, an erectors' cradle was fitted with side frames, each to take several panels or sheets. The cradle was raised into position by a power winch, and panels were fixed by bolts which were

Fig. 17



RELATIONSHIP BETWEEN AXIAL FORCE IN SUPPORTING STRUT AND LOAD AND LIFT OF JACK

placed by erectors operating from the cradle, the nuts being screwed on by men inside the structure using power-operated spanners.

Figs 18 and *19* show the Skylon by day and night.

The Paper is accompanied by nine photographs and seven sheets of drawings, from which the half-tone page plates, Plate 1, and the Figures in the text have been prepared; and by three Appendices, one of which has been incorporated in *Fig. 17* and Table 1.

APPENDIX I

CALCULATION FOR STRUTS, SHOWING THE REASONS FOR OMITTING THE SIDE STAYS

When a column that is hinged top and bottom is loaded, it is common practice to give it direction-fixing both at the top and the bottom; otherwise, the slightest unforeseen movement would result in an ever-increasing overturning moment.

The following calculation will show that a member in tension can restrain another member, in a plane at 90 degrees to it, in such a way that any movement at the top of the second member arising from unforeseen sideway forces, is not increased but actually decreased.

Two different cases have to be investigated :—

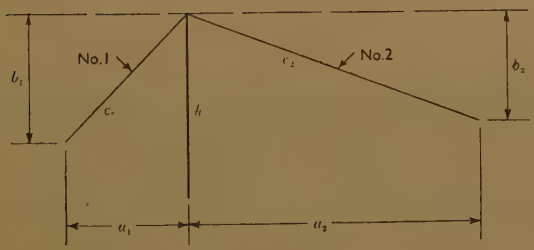
1. Where the tensile member itself forms an angle so that it exerts a considerable compression force on the first member (see *Fig. 20*).
2. Where the tensile member is in one line, so that its own stress is independent of that of the column (see *Fig. 21*).

Assume a column of height h, held at the top by two guys as shown in *Fig. 22*, and assume that the two guys are pre-stressed so that a compression force is produced in the column.

Fig. 20

Fig. 21

Fig. 22



The forces in the tensile system are in a certain geometrical proportion, following the equilibrium of the forces. If the forces in the inclined guys are T_1 and T_2, and V in the column, then :

$$T_1 = V\frac{c_1 a_2}{b_1 a_2 + a_1 b_2} \qquad \ldots\ldots\ldots (1)$$

$$T_2 = V\frac{c_2 a_1}{b_1 a_2 + a_1 b_2}$$

If there is an additional external load P on the column, the column load is $V + P$ Assuming that the top of the column moves sideways by an amount ϵ then member No. 1 in *Fig. 22* will be lengthened from c_1 to $\sqrt{{c_1}^2 + \epsilon^2}$ or $c_1\sqrt{1 + \frac{\epsilon^2}{{c_1}^2}}$.

Since $\frac{\epsilon}{c_1}$ is small, then :

$$c_1\sqrt{1 + \frac{\epsilon^2}{{c_1}^2}} c_1 = \left(1 + \frac{\epsilon^2}{2{c_1}^2}\right) \text{ (the first approximation).}$$

The new value of T_1 then becomes T_1' where

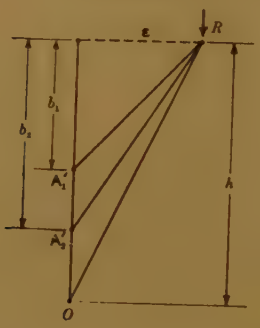
$$\left.\begin{aligned} T_1' &= T_1 + \frac{\epsilon^2}{2c_1}\cdot\frac{EA_1}{c_1} = T_1 + \frac{\epsilon^2 EA_1}{2c_1} \\ \text{Similarly} \quad T_2' &= T_2 + \frac{\epsilon^2 EA_2}{2{c_2}^2} \end{aligned}\right\} \qquad \ldots\ldots (2)$$

The tension in member No. 1 (*Fig. 22*) will tend to turn the column back. The

vertical component $T_1' \frac{b_1}{c_1}$ will actually work at a slight angle, on the line A_1 (see *Fig. 23*) and its horizontal component at R will be :

$$T_1' \frac{b_1}{c_1} \frac{\epsilon}{b_1} = T_1' \frac{\epsilon}{c_1}$$

Fig. 23



and allowing for the same effect from member No. 2 (*Fig. 22*), the actual overturning moment will be :

$$M = P\epsilon + \left(T_1' \frac{b_1}{c_1} + T_2' \frac{c_2}{c_2}\right)\epsilon - \left(\frac{T_1'}{c_1} + \frac{T_2'}{c_2}\right)\epsilon h \quad . \quad . \quad . \quad . \quad (3)$$

$$= \epsilon\left[P + T_1' \frac{b_1}{c_1} + T_2' \frac{b_2}{c_2} - \left(\frac{T_1' h}{c_1} + \frac{T_2' h}{c_2}\right)\right]$$

or, expressing T_1' and T_2' in terms of V :

$$M = \epsilon\left[P + V + \frac{\epsilon^2 EA}{2c_2^3}(b_2 + b_1 - 2L) - \frac{h(a_1 + a_2)}{b_1 a_2 + a_1 b_2} V\right]$$

or, neglecting terms in $\frac{\epsilon^2}{c^3}$:

$$M = \epsilon\left[P + V - \frac{h(a_1 + a_2)}{b_1 a_2 + a_1 b_2} V\right] \quad . \quad . \quad . \quad . \quad . \quad (4)$$

This can be expressed in a different way.

$$\text{If } V > \frac{P}{\dfrac{h(a_1 + a_2)}{b_1 a_2 + a_1 b_2} - 1} = \frac{P(b_1 a_2 + a_1 b_2)}{a_1(h - b_2) + a_2(h - b_1)} \quad . \quad . \quad . \quad (5)$$

the structure will be stable and, after any unforeseen movement, will return to its original position.

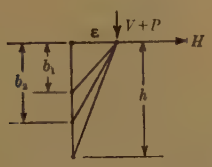
It should be noted that, if $a_1(h - b_2) + a_2(h - b_1)$ is positive, it is possible to find a pre-stressing force V which renders the system stable. Geometrically, this condition means that, for the Skylon, the line connecting the anchorage points of cables must intersect at a point higher than its base.

Alternatively, if the external load P disappears, any pre-stressing force V will be sufficient, provided the above condition is fulfilled.

Effect of Side Thrust

If, owing to wind or other causes, a side thrust H occurs (*see Fig. 24*), in addition to the above-mentioned pre-stressing and the external force P, the overturning moment would be :

Fig. 24



$$M = \epsilon\left[P + V\left(1 - \frac{h(a_1 + a_2)}{b_1a_2 + a_1b_2}\right)\right] + Hh \quad . \quad . \quad . \quad . \quad (6)$$

In this case the sign of M depends upon the magnitude of ϵ. On the other hand, the deflexion ϵ is no longer accidental, but can be calculated from the load H. Assuming ϵ to be known, the forces T_1 and T_2 can be considered to be the sum of those forces produced by pre-stressing and shown in formulae (2) and those produced by H. The part of the force produced by H may be calculated by the following formulae.

$$\left(\frac{T_1}{c_1} + \frac{T_2}{c_2}\right) \cdot \epsilon \cdot \frac{(h - b_1)a_2 + (h - b_2)a_1}{a_1 + a_2} = Hh$$

$$\frac{T_1}{c_1}a_1 = \frac{T_2}{c_2}a_2$$

$$\left.\begin{aligned} T_1 &= \frac{Hha_2c_1}{\epsilon[(h - b_1)a_2 + (h - b_2)a_1]} \\ T_2 &= \frac{Hha_1c_2}{\epsilon[(h - b_1)a_2 + (h - b_2)a_1]} \end{aligned}\right\} \text{caused by } H \quad . \quad . \quad (7)$$

The total extension of the guys must be equal to the geometrical extension.

The total extension is, of course, $\frac{T_1c_1}{AE} + \frac{T_2c_2}{AE}$ where T_1 and T_2 are the additional forces caused by pre-stressing and H.

The geometrical extension is :

$$\sqrt{c_1^2 + \epsilon^2} + \sqrt{c_2^2 + \epsilon^2} - c_1 - c_2 \quad . \quad . \quad . \quad . \quad . \quad (8)$$

But $\frac{\epsilon}{c_1}$ and $\frac{\epsilon}{c_2}$ are very small, and the first approximation is :

$$c_1\sqrt{1 + \frac{\epsilon^2}{c_1^2}} + c_2\sqrt{1 - \frac{\epsilon^2}{c_2^2}} - c_1 - c_2$$

The total extension, therefore, becomes :

$$\frac{T_1c_1 + T_2c_2}{AE} = \frac{\epsilon^2}{2c_1} + \frac{\epsilon^2}{2c_2} = \frac{\epsilon^2}{2c_1c_2}(c_1 + c_2)$$

Replacing the total extension by formulae (7) and (1) :

$$\frac{Hh}{\epsilon[(h - b_1)a_2 + (h - b_2)a_1]}(a_2c_1^2 + a_1c_2^2) - \frac{V}{b_1a_2 + a_1b_2}(a_2c_1^2 + a_1c_2^2) = \epsilon^2\frac{EA}{2}\left(\frac{c_1 + c_2}{c_1c_2}\right) \quad . \quad . \quad . \quad (9)$$

This equation is of third degree for ϵ. It can be solved numerically and ϵ be substituted in equation (4).

In many cases V is large enough for the term in ϵ^2 to be neglected. (This means that a cable that is pre-stressed to an appreciable amount is not subjected to additional stresses by comparatively small horizontal forces, and this is confirmed by calculated examples). In this case :

$$\frac{Hh}{\epsilon[(h-b_1)a_2+(h-b_2)a_1]} = \frac{V}{b_1a_2+a_1b_2}$$

$$V = \frac{Hh(b_1a_2+a_1b_2)}{\epsilon[(h-b_1)a_2+(h-b_2)a_1]} \quad . \quad . \quad . \quad . \quad (10)$$

Substituting in (7), as was to be expected, the old values for T_1 and T_2 are derived.

Again the pre-stressing force can be chosen to keep ϵ within certain limits. (For the Skylon $\epsilon = 5$ inches).

This case is of no practical importance for the struts of the Skylon, because the straight cable can be completely unstressed under full wind force, and therefore it does not help in keeping the head of the strut in position. It is given here, however, for general interest.

Figs 25

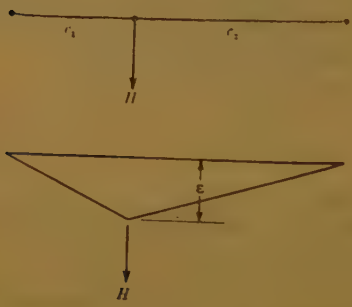


Fig. 26

Assuming a tensile force T_0 in the straight cable (neglecting the effect of its own weight) and a sideways force H (see *Figs 25*), then:

$$T\epsilon = \frac{Hc_1c_2}{c_1+c_2}$$

$$\frac{(T-T_0)(c_1+c_2)}{EA} = \sqrt{c_1^2+\epsilon^2}+\sqrt{c_2^2+\epsilon^2}-c_1-c_2$$

$$= \frac{\epsilon^2}{2c_1c_2}(c_1+c_2) \quad . \quad . \quad . \quad . \quad . \quad . \quad (11)$$

(see equation (8))

which reduces to:

$$T - T_0 = \frac{EA\epsilon^2}{2c_1c_2}$$

Combining this with equation (11) gives:

$$\left(\frac{Hc_1c_2}{\epsilon(c_1+c_2)} - T_0\right) = \frac{EA\epsilon^2}{2c_1c_2} \quad . \quad . \quad . \quad . \quad . \quad . \quad (12)$$

which again is an equation of third degree for ϵ from which T can be found. The rectifying force in this case is

$$T\epsilon\left(\frac{1}{c_1}+\frac{1}{c_2}\right) = \frac{T\epsilon(c_1+c_2)}{c_1c_2}$$

If a force P acts on a member of height h (see *Fig. 26*), then:

$$\text{total moment} \quad M = P\epsilon - T\epsilon h\frac{c_1+c_2}{c_1c_2}$$

This is negative when $T > \frac{Pc_1c_2}{h(c_1+c_2)}$, which indicates stability.

APPENDIX II

DETERMINATION OF WIND FORCES

The following were available, to be used as bases for determining the wind load:—

A. Code of Practice, Chapter V (Loading).
B. Calculations, based on published information about the pressure distribution, due to wind, on circular objects.
C. Experiments made in a wind tunnel on a section closely resembling that of the Skylon.

A. *Code of Practice*

For southern and eastern England, in open country, at a height of about 40 feet the following velocity is suggested : $V = 65$ miles per hour.

At a height of approximately 200 feet this corresponds to a velocity of 123·5 miles per hour or 181 feet per second.

Allowing a reduction factor of 0·7 because the cross-section is only approximately circular, the corresponding wind pressure would be :

$$p = 0{\cdot}7 \times 25{\cdot}4 = 17{\cdot}8 \text{ lb. per square foot.}$$

B. *Published Information*

(*a*) Dryden and Hill, " Wind Pressures on Circular Chimneys and Cylinders." U.S. Bureau of Standard Research, Report 221.
(*b*) Distribution of Forces in accordance with Flachsbart.
(*c*) Flachsbart's distribution as simplified by Guthlac Wilson in " The Encasing Structures for the Hot Water Accumulator for the Pimlico District Heating Scheme." (*Structural Engineer*, vol. xxviii, p. 85 (April 1950).)

A new approximation curve was adopted, following Guthlac Wilson's for the windward side, but approximating more to the Flachsbart curve for the leeward side.

Fig. 4 shows the approximate pressure, based on a total pressure of 25 lb. per square foot (see A), plotted against an angle increasing from 0 to π.

Fig. 5 shows the same pressure distribution plotted against a circle and compared with Flachsbart's curve (broken lines).

Total pressure per foot of height, $p' = 2\int_0^{\pi} pr \cos\alpha \, . \, d\alpha$

Pressure on projected area $= \dfrac{p'}{2r} = \displaystyle\int_0^{\pi} p \cos\alpha \, . \, d\alpha$

$$= 25\int_0^{\frac{\pi}{12}} \cos\alpha \, . \, d\alpha + \frac{125}{3}\int_0^{\frac{1\pi}{24}} \cos\alpha \, . \, d\alpha - \frac{200}{\pi}\int_{\frac{\pi}{12}}^{\frac{11\pi}{24}} \alpha \cos\alpha \, . \, d\alpha$$

$$- 50\int_{\frac{11\pi}{24}}^{\frac{\pi}{2}} \cos\alpha \, . \, d\alpha + \frac{160}{\pi}\int_{\frac{\pi}{2}}^{\frac{3\pi}{4}} \alpha \cos\alpha \, . \, d\alpha - 130\int_{\frac{\pi}{2}}^{\frac{3\pi}{4}} \cos\alpha \, . \, d\alpha$$

$$- 10\int_{\frac{3\pi}{4}}^{\pi} \cos\alpha \, . \, d\alpha$$

$$= 17{\cdot}12 \text{ lb. per square foot.}$$

C. *Experiments in Wind Tunnel*

In view of the fact that the cross-section of the Skylon is not circular but duodecagonal, and that the surface is not completely closed in, tests were carried out by

Professor N. A. V. Piercy at Queen Mary College, London, on a "closed" model approximating to the centre part of the Skylon, and on an "open model" approximating to the ends.

According to the report issued by Professor Piercy, for a wind of 75 miles per hour the closed model showed a pressure of 17·5 lb. per square foot and the open model 14·5 lb. per square foot.

The Meteorological Office gave a wind velocity of 80 miles per hour as being the maximum to be expected at a height approximating to the top of the Skylon (in London) and, correcting the figures in the proportion of 75 to 80, the forces were :

$$14{\cdot}5\,\frac{80^2}{75^2} = 16{\cdot}5 \text{ lb. per square foot}$$

and

$$17{\cdot}5\,\frac{80^2}{75^2} = 19{\cdot}8 \text{ lb. per square foot.}$$

Since the major part of the Skylon is "closed", a figure between 16·5 and 19·8 was taken as being adequate. To be on the safe side, the figure was taken as 19·4 lb. per square foot.

Summary

	lb. per square foot
Pressure, according to Code of Practice	17·8
Pressure according to calculations	17·12
Pressure in accordance with wind tunnel test	16·5 to 19·8
Pressure selected for actual design	19·4

Shock and Resonance Factor

Previous tests carried out by Professor Piercy at the Queen Mary College showed that, with frequencies above 2·8 cycles per second there was no need to introduce a shock factor, whilst with a frequency of 0·5 cycle per second a factor of 1·8 should be introduced.

Calculation showed that the frequency of full vibration of the Skylon was 1·02 vibration per second, which by interpolation, gave a factor of 1·6.

The actual pressure used for the design, is, therefore :—

$19{\cdot}4 \times 1{\cdot}6 = 31$ lb. per square foot (calculated on the projected area)

THE SKYLON

FIG. 3

KEY TO COMPONENTS

1. Central feature
2. Supporting strut
3. Wind stay
4. Supporting pennant
5. Cable anchorage
6. Hinged jacking Lever
7. Spider unit
8. Spiral ladder
9. Stiffening frame
10. Platform landings
11. Cable bearing: sheaves and clamps
12. Hydraulic jack
13. Ball-located rocker bearing

Published in Proceedings, Part I, May 1952

Paper No. 5851

' Civil Engineering Aspects of Hydro-Electric Development in Scotland ''

by

Angus Anderson Fulton, B.Sc., M.I.C.E.

Sir Murdoch MacDonald remarked that the reading of the mass of all the material available to engineers dealing with the subjects in which they specialized was difficult. Study of Mr Fulton's Paper, however, by all members of the profession was essential. The reason was that it was not only the duty of those engineers who specialized in that particular branch of the profession, but also of all others as well, to be protagonists in the matter of impressing everyone with whom they came in contact that hydro-electric work was of essential value to the community.

Rain, the basal requirement in hydro-electric work (although the tides might one day reinforce it), could always be counted upon in hilly Scotland, where it now fell in ample volume. In all probability the climate would not change until a far far distant day.

The Author had put the matter clearly and emphatically when he stated that " a small country with limited water power resources *must* turn every available stream to account."

The italics were Sir Murdoch's—to draw attention to the emphasis he laid on the matter. The Author need hardly have added the word " small," because its omission in the sentence would still further strengthen his valuable statement.

In the present age coal and oil were both wasting assets. The world's population also was increasing so rapidly that it was doubtful if food would remain cheap and if in such a country as Great Britain, work could continue to pay for it and maintain the present standard of living.

Thus every interest that man could have justified the Author's pronouncement. It required stating again and again to overcome the resistance to change which moved many to object to hydro-electric schemes. Sir Murdoch hoped, therefore, that all engineers, without any thought of the direct, though after all temporary, benefit any of their professional brethren might acquire in the matter, would point out to all and sundry the knowledge which their professional position had enabled them to gather through such a Paper. For the first time, so far as he knew, had the essentiality of such work been so clearly and definitely stated as it had been by the Author.

The Author expressed his appreciation of Sir Murdoch's remarks and stated that there was no comment he could usefully add to them.

REPORT OF THE COUNCIL AND STATEMENT OF ACCOUNTS 1951–52*

In presenting the Annual Report upon the state of the Institution the Council wish to record the deep sense of loss which has been experienced by members in the death of His Majesty King George VI, Patron of the Institution. His late Majesty won the esteem and affection of his subjects by the dignity of his bearing in all the difficulties and dangers which beset his reign, by his loyal and steadfast devotion to duty, and by the tenor of his family life. Addresses of condolence and of loyalty have been transmitted on behalf of the members of the Institution to Her Majesty Queen Elizabeth II and to Her Majesty Queen Elizabeth, the Queen Mother.

The Council have much pleasure in recording that His Royal Highness Philip, Duke of Edinburgh, has graciously consented to become an Honorary Member and was elected by the members at an Ordinary Meeting on the 22nd January, 1952. The President, accompanied by the Senior Vice-President and the immediate Past-President, had the honour of being received by His Royal Highness on the 17th March and of presenting the Diploma of Election. His Royal Highness signed the Roll of Honorary Members.

Amendments to the By-Laws.—In last year's Report the Council referred to certain proposed changes in the By-laws which were to be submitted to the Corporate Members for their approval and sanction. A schedule of the proposed alterations was issued last summer and on the 20th December, 1951, a Special General Meeting of the Corporate Members was held at the Institution, when, after taking into account the votes received by post, the President from the Chair announced that the Resolutions embodying the amendments had been passed by large majorities.

The approval of the Privy Council to these alterations has been received and the revised By-laws became operative on the 24th March, 1952. Among the alterations are By-laws setting up a new class of Graduates.† This class of membership is an intermediate one between Studentship and Associate Membership. Persons between the ages of 21 and 28 years may enter this class and as Graduates may remain on the Roll until they are 32 years of age. The qualifications for entry require that applicants should be in the course of training for, or of obtaining experience in, civil engineer-

* Presented to the Annual General Meeting, 10 June, 1952. An account of that meeting is printed as an inset with this number of Part I of the Proceedings.—SEC. I.C.E.

† The Council have pleasure in stating that at their meeting on the 20th May, which is subsequent to the period covered by this Report, the first Graduates were admitted to the number of 264.

ing, and should have either obtained an engineering degree recognized by the Council or have passed both parts of the Institution Examination.

All those Students who, under the By-laws, reached the age limit for that class this year but are now eligible for Graduateship have been notified.

What were known as Sections A and B of the Associate Membership Examination will now be called Final Parts I and II of the Institution Examination. The requirements for the Professional Interview, which replaces Section C, remain the same.

There has been a change also in the procedure for the election of Associate Members. Instead of ballots being held at Ordinary Meetings the Council will publish, from time to time, in *Chartered Civil Engineer*, a list of candidates for election together with an intimation that they are prepared to receive for consideration communications from Corporate Members respecting the qualifications and character of any candidate. The new By-laws state that after the lapse of at least one month from the date of publication the Council may declare the candidate elected if satisfied that he is a fit and proper person to become a Corporate Member. The Council have ruled that any such communications must be lodged with the Secretary immediately upon receipt of the notice and by air mail if the Corporate Member is overseas.

Publications.—On the 1st January, 1952, certain important changes in the issue of the Institution publications came into force. Under the new scheme the term " Journal " has ceased to be used and the publications are issued monthly in three Parts under the title of " Proceedings of the Institution of Civil Engineers." Part I is being issued in the months of January, March, May, July, September, and November to all Corporate Members, Associates, Graduates, and Students without charge, and will include the Presidential Address, Papers, and discussions in connexion with Ordinary Meetings, Special Lectures, certain Papers printed with written discussion only, and the Annual Report. An issue of *Chartered Civil Engineer* will be made with each number of Part I of the Proceedings. Part II is being issued in the months of February, June, and October at an annual charge of 10/- and includes all Papers presented at Meetings of the Airport, Maritime, Railway, and Road Engineering Divisions, and the oral and written discussions, together with any theoretical Papers printed with written discussion only, which are regarded as appropriate to these Divisions. Part III is being issued in the months of April, August, and December, at an annual charge of 10/-, and includes all Papers presented and discussed at the Meetings of the Public Health, Structural and Building, and Works Construction Engineering Divisions, and the oral and written discussions, together with any theoretical Papers, printed with written discussion only, which are regarded as appropriate to these Divisions.

In addition to the above, a limited number of separate pamphlet copies of each Paper published in Parts I, II, and III of the Proceedings

will be available and copies may be obtained from the Secretary at a charge of 2/- per pamphlet.

This three-Part scheme has, the Council consider, met with the approval of members and the demands for Parts II and III are satisfactory and steadily increasing.

Géotechnique, the International Journal of Soil Mechanics, is now published quarterly instead of twice yearly; the annual subscription remains unchanged.

Meetings.—Seven Ordinary, one Supplementary, and twenty-four Divisional Meetings have been held. A list of the Papers, Lectures, and Discussions at such meetings will be found in Appendix I. The awards for Papers presented at Ordinary and Divisional Meetings will be announced at the Opening Meeting next Session.

The Opening Meeting of Session 1951–52 was held on the 6th November when Mr Allan S. Quartermaine, in his Presidential Address, dealt with the works of I. K. Brunel on the Great Western Railway, the complex nature of present-day railways, and the opportunities afforded to railway civil engineers.

Engineering Divisions.—The seven Engineering Divisions (Airport, Maritime and Waterways, Public Health, Railway, Road, Structural and Building, and Works Construction) held twenty-four meetings, at one of which a Lecture was delivered to the Public Health Division, and at two of such meetings Introductory Notes were followed by discussions on subjects of interest to the Railway Division.

Visits were paid to the Woodhead new tunnel (Railway Division); new hangars at London Airport (Structural and Building Division); Crawley New Town (Public Health Division); the Society of British Aircraft Constructors' display and exhibition at Farnborough (Airport Division); the Mersey docks, and also the port of Le Havre (Maritime and Waterways Division); the new oil refinery, Isle of Grain (Works Construction Division); and the Military Experimental Bridging Establishment, Christchurch (Road Division).

Registration of members in the Divisions ceased on the 1st January, the Council being of the opinion that registration was no longer necessary in view of the fact that Parts II and III of the Proceedings take the place of the issue of separate pamphlet copies of Divisional Papers to the members. Each Division will, of course, continue to function as hitherto by holding meetings and by arranging for visits to works.

Local Associations.—The activities of the Local Associations have received the special attention of the Council during the past year, following certain inquiries which were made as to the best means of improving the attendances at Association meetings and visits to works, of stimulating the interest of Students in the affairs of the Associations, and of ensuring that the Papers and Lectures were such as to attract all grades of membership.

Each Association was invited to send in suggestions and the response was most helpful. As a result, a comprehensive list of suggestions was compiled and circulated to all the Local Associations, though it was made clear that the suggestions were only for adoption after their respective Committees had decided whether or not they were suitable, having regard to the special conditions in each area.

The Council, for their part, also arranged to implement those suggestions which called for action by the Institution itself. One of these suggestions was that greater space should be given in the Annual Report to the activities of Local Associations. Thus a short account of each Association has been included in Appendix II.

The Council have decided to extend the award of the Institution Medal to Students who are members of Local Associations. A competition will be held annually in London, on lines similar to the existing one, which is restricted to undergraduates of London University.

There have been several changes among the Honorary Secretaries, namely, Mr G. C. Mander has replaced Mr B. E. Ireland at Bristol; Mr H. B. Roberts has replaced Mr J. R. Roberts at Leeds; Mr T. L. Lowe has replaced Mr D. Lumbard at Cardiff; and at Belfast, Mr R. D. Fitzgerald replaced Mr E. H. Sidwell temporarily, during the latter's absence abroad. The Council wish to place on record their high appreciation of the work done by these individuals, making particular mention of Mr J. R. Roberts, who held the appointment for seven years. The work done by the Honorary Secretaries and their Assistant Honorary Secretaries is greatly valued by the Council.

Awards for Students' Papers read before Local Associations, made by the Council for Session 1950–51 and announced early this Session,[1] consist of two Miller Prizes to Student Members of the Edinburgh and East of Scotland and of the South Western Associations respectively; a James Prescott Joule Medal and a Miller Prize to a Student Member of the Glasgow and West of Scotland Association; and a Miller Prize to a Student Member of each of the following: Northern Counties, Midlands, Southern, and South Wales and Monmouthshire Associations.

The Dugald Clerk Lecture on "Tunnelling Plant and Equipment," by G. C. Archer, was, by arrangement of the Council, delivered before the North Western, Northern Counties, Northern Ireland, South Western, Glasgow and West of Scotland, and Yorkshire Associations.

Overseas Associations.—The Buenos Aires Association has now been formally dissolved consequent upon the formation of the Joint Overseas Group in the Argentine.

The membership of the Victoria Association now totals 127 and shows an increase on last year's figure which was itself a record. The activities of the Association have included an evening function with technical films; two luncheons; and a visit to the Kiewa works of the State Electricity

[1] Proc. Instn Civ. Engrs, Part 1, Vol. 1, p. 26 (Jan. 1952).

Commission. The Committee of the management met four times during the year and contact has been made with members resident in South Australia with beneficial results.

The Trinidad Branch of the West Indies Association has held a total of twelve meetings, including three jointly with the Institution of Mechanical Engineers and two with the Institution of Electrical Engineers. The annual Dinner of the Branch was held on the 1st February, 1952, at the Bel Air Hotel, Piarco. Excellent relations with the Institution of Mechanical Engineers and Institution of Electrical Engineers continue to exist locally and on the 11th December, 1951, a Joint Programme Committee was formed with these bodies.

Joint Overseas Groups.—The activities of the Abadan Joint Overseas Group have been in abeyance following events in Iran, but the Committee is continuing to function and is keeping in touch with members while it awaits developments.

In view of the fact that it was not considered appropriate to hold an election for the new Committee, the present Committee, with Mr A. Morrison, M.I.Mech.E., as Chairman, and Mr T. L. Stephens, B.Sc.(Eng)., A.M.I.E.E., as Honorary Secretary, is continuing in office.

The Argentine Joint Overseas Group continues its activities and the Chairman for the year is Mr Alan C. Towers, M.I.E.E., who succeeded Mr F. W. Butler, B.Sc.(Eng.), M.I.C.E. The Honorary Secretary is Mr J. H. Robinson, A.M.I.Mech.E.

The Association of London Students.—The Opening Meeting was held on the 7th November, when the Chairman of the Committee of the Association, Mr P. J. Mulligan, Stud.I.C.E., delivered an Address on "District Heating and Other Engineering Works." On the 2nd January, the Dugald Clerk Lecture, on "Tunnelling Plant and Equipment," was delivered by Mr G. C. Archer. An Extraordinary General Meeting was held in January to consider the revision of the rules of the Association, and the Annual General Meeting was held on the 23rd April. Three meetings were held for the reading and discussion of Papers. In addition a Debate was held at the Institution with the Students' and Graduates' Sections of the Institutions of Mechanical and Electrical Engineers; an Informal Address on "Construction Methods in Pre-stressed Concrete" was given by Mr W. M. Johns, M.C., B.Sc.(Eng.), A.M.I.C.E.; and a Student gave a talk on American civil engineering. The Council note with pleasure that the attendances at the various meetings of the Association continue to be very good.

Ten visits were paid to engineering works during the Session. In addition the Committee organized a number of other visits, including a summer tour of civil engineering works in Scotland. A Smoking Concert and a joint Dance with the Graduates' and Students' sections of the Institutions of Mechanical and Electrical Engineers were also held.

It has been announced that a Miller Prize was awarded to Arthur

Marsland, B.Sc., Stud.I.C.E., for his Paper, presented last Session, on "The Influence of Groundwater Flow on the Stability of Civil Engineering Structures and Earthworks."

Institution Entries.—Between 1st April, 1951, and 31st March, 1952, 902 new applications for election were received, as compared with 870 last year, and were considered together with 246 (320 in 1950–51) deferred from previous years. During the same period, 7 (2 in 1950–51) were elected full Members and 704 (716 in 1950–51), Associate Members. Of the latter, 441 were Engineering Graduates of a University recognized by the Institution: thus, the number of University Graduates entering the Institution as Associate Members was 62·6 per cent of the whole entry as compared with 54·5 per cent in the Session 1936–37.

The Council think it desirable to give some particulars of the methods adopted by persons studying for the Associate Membership Examination.

Prior to the war the Candidates for the Associate Membership Examination received tuition privately, or by attending classes for the purpose at certain Technical Colleges, or by Correspondence Courses. There are unfortunately no figures to show the proportions adopting these different methods but there is reason to believe that well over half made use of Correspondence Courses.

In March 1943 the Council entered into negotiations with the Board of Education for setting up a Higher National Certificate in Civil Engineering, the intention being that in due course this Certificate would be recognized on a subject-for-subject basis as exempting from Sections A and B of the Associate Membership Examination. The conditions of award were accepted not only as between the Institution and the Board of Education but also as between the Institution and the Scottish Education Department. It may be noted that any one commencing studies for the Higher National Certificates had first to obtain an Ordinary National Certificate in Mechanical or Electrical Engineering or else in Building. Owing to the war, little progress was made in this important development, but in recent years its effect has become sufficiently pronounced as to warrant reference in the Council's Report. Thus, in the past three years Higher National Certificates have been awarded in England and Scotland to 37 (1949), 67 (1950), and 100 (1951) successful candidates.

The following Technical Colleges operate approved Evening Class Courses under the Scheme, and are prepared to include part-time day tuition in cases where sufficient employers grant individuals one day (or two afternoons) release each week:—

In London:

Battersea Polytechnic;
Brixton School of Building;
The Polytechnic, Regent Street;
Northampton Polytechnic;
Westminster Technical College;

In the Provinces :

Birmingham Central Technical College ;
Bradford Technical College ;
Brighton Technical College ;
Derby Technical College ;
Dudley and Staffordshire County Technical College ;
Kingston Technical College ;
Liverpool College of Technology ;
College of Technology, Manchester ;
Mansfield Technical College ;
Constantine Technical College, Middlesbrough ;
Municipal Technical College, Nottingham ;
Plymouth and Devonport Technical College ;
Harris Institute (Preston) ;
St Helens Municipal Technical College ;
Wigan and District Mining Technical College.

In Scotland :

Robert Gordon's Technical College, Aberdeen ;
Heriot-Watt College, Edinburgh ;
Royal Technical College, Glasgow.

In addition, Brighton Technical College, Loughborough College, and Robert Gordon's Technical College each award Diplomas in Engineering after three years' full-time study, which are recognized by the Council as exempting from Section A and B of the Associate Membership Examination. The essential feature of the Diplomas at Brighton and Loughborough is that the Examinations are moderated by representatives of the Institution, whilst the Diploma awarded at Robert Gordon College is associated with the University of Aberdeen.

The Council welcome this increase in the numbers of non-University candidates obtaining exemption from the Institution Examinations through Higher National Certificates in Civil Engineering, since the Courses are strictly controlled by H.M. Inspectors in conjunction with the Institution and are therefore far in advance of other means of tuition for such candidates, particularly that obtained through Correspondence Courses.

An analysis of the Joint Section A Examination held in October 1951 shows that, of the 216 candidates, 118 (55 per cent) attended Technical Colleges, 80 (37 per cent) were prepared by Correspondence Courses, 6 (2·5 per cent) by private tuition, and 12 (5·5 per cent) by a combination of these forms of teaching. The performance of the candidates in these groups is given in the table on next page.

The number of failures is high and the Council are of opinion that many young men enter for the Examinations before they are adequately prepared, and, further, that Correspondence Courses are not adapted to the needs of young engineers, since in this particular examination 73 per cent

	Technical College	Correspondence Courses	Other means of tuition for such Candidates	Totals
Passed whole exam.	40 (34%)	18 (23%)	4 (22%)	62
Passed one subject	4 (3%)	3 (4%)	2 (11%)	9
Failed	53 (45%)	49 (61%)	8 (45%)	110
Referred	21 (18%)	10 (12%)	4 (22%)	35
Totals	118	80	18	216

approximately of the Correspondence Courses entrants either failed or were referred. Postal Tuition cannot be regarded as so effective as a course of study under the direct and personal supervision of a teacher with systematic laboratory as well as class work. The Council are of opinion that the young engineer who is about to decide on the method he will adopt for his engineering studies should take note of the successes of the Technical Colleges and of the advantages they offer as compared with Correspondence Courses.

In conclusion, the following table gives particulars of passes and failures in the Associate Membership Examination for the year 1951 :—

SECTIONS A, B, AND C OF THE ASSOCIATE MEMBERSHIP EXAMINATION APRIL 1951 AND OCTOBER 1951

	Number taking part		Passes		Failures	
	Home	Abroad	Home	Abroad	Home	Abroad
Joint Section A.	579	123	185	46	394	77
Section B.	299	55	177	23	122	32
Section C.*	670	153	584	118	86	35

* It should be noted that more than half the candidates taking Section C are exempt from Sections A and B by possession of a University Degree or other qualification.

Bayliss Prize.—For the April 1951 Examination, the Bayliss Prize was awarded to Mr D. G. Llanwarne (London), an approved candidate for election, and for the October 1951 Examination to Mr K. G. Aubrey (Australia) and Mr L. D. Bedford (New Zealand), both Students of the Institution who obtained equal marks. Mr D. B. Cook (London), Stud.I.C.E., who obtained third place, was given Honourable Mention.

Transfers.—Between 1st April, 1951, and 31st March, 1952, the Council considered 115 applications for transfer from Associate Membership to full Membership, of which 82 were approved.

Research.—During the year two new Committees have been appointed and three Committees have been dissolved. The following is a summary of the work of the Research Committee :—

Breathing Apparatus.—A Report on Safety Measures in Sewers prepared by the Committee has been published and the Committee has been dissolved.

Erosion of Earthen Banks.—Data on the overtopping of earthen banks collected by the Committee are now being collated and a report is being prepared. Experiments are continuing on the suitability of various grass seed mixtures and the formulation of a test for the resistance to erosion of soils.

Compressed Air.—Comments on the revised Preliminary Draft Regulations issued under the Factories Act for Work of Engineering Construction have been submitted to the Ministry of Labour Factories Department.

Performance of Concrete-Mixing Machinery.—The results of experimental work at the Road Research Laboratory have been reviewed but the Committee is not yet in a position to prepare a report.

Soil Mechanics and Foundations.—A supplement to the Bibliography on Soil Mechanics for 1950 has been published and supplements for 1951 and 1952 are in course of preparation.

Engineering Bills of Quantities.—A draft report revising the Report of the Committee on Engineering Quantities published in 1933 has been prepared. The draft report was circulated for comment to the Local Associations and these comments are now being considered.

Mechanical Properties of Aggregates.—The preparation of a report dealing with the methods of testing the aggregates for structures other than roads is now well advanced.

Pre-stressed Concrete Development.—As a result of the suggestion of the Committee a discussion was held at the Institution on the Relative Economics of Pre-stressed Concrete compared with Reinforced Concrete, Steel, and other Forms of Construction. The Committee is undertaking a review of existing structures in pre-stressed concrete to see if from their behaviour any data could be obtained on the corrosion of steel in pre-stressed concrete structures. A Bibliography on Pre-stressed Concrete, covering the period up to 1950, has been published and supplements for the years 1951 and 1952 are in course of preparation.

Pile Driving.—In response to the request of the Committee some field observations on the driving characteristics and static bearing capacities of full-size piles and pile groups have been received, but the Committee is most anxious to receive further information on this subject from members.

Quality of Concrete in the Field.—The work of this Committee is well advanced and consideration has been given to the degree of quality control required in relation to concrete strength requirements and the size of the works. Consideration has also been given to the precautions to be taken by workmen in the production of concrete.

Sea Action.—A revised edition of the Nineteenth Report of the Committee has been published. This edition gives the final results of the series of experiments started in 1939 at Colombo and Singapore, on the preservation of timber. Tests on timber started in 1949 at Colombo, Singapore, and Upnor are continuing.

Soil Corrosion of Metals and Cement Products.—There is no further progress to report in connexion with this work.

Vibrated Concrete.—A considerable amount of data has been collected by this Committee and the preparation of a draft report has been started.

Coast Protection.—The Committee is reviewing the problems in connexion with coast protection which require to be solved.

Hydraulics Committee.—A new Committee has been appointed to keep in touch with developments and to appoint ad hoc Sub-Committees to deal with any points that may arise within its sphere of interest. The Committee has also been instructed to prepare a review outlining recent developments in the sphere of hydraulics both in the field and in laboratories. As a result of the appointment of this Committee, the Committee on Velocity Formulae for Open Channels and Pipes and the Committee on Rainfall, Run-off, and Floods have been dissolved. The work previously done by these two Committees will now be undertaken by the new Committee on Hydraulics.

Mining Subsidence.—A new Committee has been appointed to examine the present state of knowledge of the effects of mining subsidence on the stability and durability of all types of civil engineering works and structures on or near the surface, including services and drainage of the area. The Committee is also to consider the manner in which research may be expected to eliminate or ameliorate these facts and has been asked to make recommendations for research.

British Standards Institution.—During the year a number of members have been invited to represent the Institution on technical committees of the British Standards Institution.

Other Technical Committees.—The Committee set up to prepare a Memorandum on the Safety Precautions recommended for Workers in Wells completed its work during the year and the Memorandum has been published.

The drafting of the Memorandum on the Construction and Equipment of Dry Docks was completed by the Special Committee set up for this purpose. The manuscript is with the printers and copies of the Memorandum will be available shortly.

Codes of Practice.—Arising from the opinions expressed in the report of the Cunliffe Committee on the Organization and Constitution of the British Standards Institution, and from the decisions reached at the Commonwealth Standards Conference of 1951, discussions have been held between the Civil Engineering Codes of Practice Joint Committee and the

British Standards Institution regarding the possibility of forming, within that Institution, a Committee to be responsible for initiating and preparing Codes of Practice in the field of Civil Engineering, whilst ensuring that final responsibility would remain with the Professional Engineering Institutions concerned. Preliminary agreement has been reached on the principles involved and discussions are taking place to see if these can be implemented in a manner satisfactory to both parties.

Code No. 2—Earth Retaining Structures—has been issued by the Institution of Structural Engineers on behalf of the Joint Committee.

Code No. 3—Earthworks—the drafts prepared by the Drafting Panels are now being considered by the Main Committee with a view to issuing a draft Code for comment during 1952.

Code No. 4—Foundations—the draft Code issued for comment has now been revised in the light of the comments received and it is hoped that the final Code will be issued in the early summer.

Code No. 5—Drainage-Sewage—has been issued by the Institution of Municipal Engineers on behalf of the Joint Committee.

Code No. 6—Traffic Bearing Structures–Pavings—the drafts prepared by the Drafting Panels are now being considered by the Main Committee with a view to issuing a draft Code for comment during 1952. The Panel appointed by the Committee to revise the Glossary of Highway Engineering Terms has held meetings regularly throughout the year and the final draft of the revision is almost complete.

Railway Engineering Abstracts.—The Abstracts have been issued monthly and an index for the year 1951 has been prepared.

Public Relations.—Three meetings of the Public Relations Committee were held during the year. The National Committee for the Use of Visual Aids in Education has expressed its willingness to co-operate in the preparation of film strips and films for use in schools. An Educational Adviser has been appointed to assist in this matter.

A further series of four lectures for groups of boys and girls was organized in co-operation with the Education Officer of the L.C.C., when about 360 boys and girls attended three lectures at the Institution of Civil Engineers and about 500 boys and girls attended one lecture at the Institution of Electrical Engineers. These were :—October 1951, " Wonders of Bridge Building," by H. Shirley Smith, O.B.E., B.Sc.(Eng.), M.I.C.E.; November 1951, " The Romance of London's Water Supply," by Tudor H. Davies, M.C., M.I.C.E.; January 1952, " Electricity—Birth of a Giant," by Professor J. Greig, M.Sc., Ph.D., M.I.E.E.; February 1952, " Airfield Construction," by C. E. Foster, C.B.E., B.Sc.(Eng.), M.I.C.E.

Three Christmas Lectures for boys were given at the Institution on " Oil." About 400 boys attended each of the following three lectures :—28 December, 1951 : " Exploring for Oil," by Dr. G. M. Lees, M.C., D.F.C., F.R.S., Chief Geologist, Anglo-Iranian Oil Co.; 31 December,

1951 : " Transporting Oil in Peace and War (Pluto)," by A. C. Hartley, C.B.E., B.Sc.(Eng.), M.I.C.E.; 2 January, 1952 : " Working of an Oil Refinery," by S. W. Adey, B.Sc., A.R.C.S.

Various University Engineering Societies made use of the Joint Panel of Lecturers, organized in co-operation with the Institution of Mechanical Engineers and the Institution of Electrical Engineers, for Lectures to their Societies.

Contact has been maintained with the British Broadcasting Corporation and the Technical and General Press. The Public Relations Committee discussed with Mr Harold Cox, Television Newsreel Manager, B.B.C., how engineers could best co-operate with them in bringing to their notice any specially interesting civil engineering work.

The Council are at present giving consideration to the whole question of the civil engineering profession and the public. They believe the public should be made better acquainted with the work done by the engineer and that much can be done by engineers themselves to bring this about. Steps have been taken to bring this view to the notice of the profession.

Engineering Public Relations Committee.—As conditions have changed since the Engineering Public Relations Committee, on which the Institution is represented, was formed in 1936, it has been decided to dissolve the Committee. It has been found that the best results were obtained by Institutions acting on their own or in co-operation with those other bodies which were likely to be specially interested in any aspect of the work.

Town and Country Planning.—A letter expressing the views of the Council on the report of the Committee on Qualifications of Planners, presided over by Sir George Schuster, was submitted to the Minister of Housing and Local Government during the year.

Accounts.—The accounts for the year ending on the 31st March, 1952, which have been duly audited, are detailed in Appendix IV of this Report and may be summarized briefly as follows :—

The *Total Income* for the year amounted to . . . £88,084
(as compared with £83,903 last year) including £552 for Income Tax recovered. Subscriptions, Entrance Fees, and Examination Fees totalled £84,872 (as compared with £81,173 last year), and Dividends and Interest received amounted to £1,976 (as compared with £1,913 last year).

The *Total Expenditure* charged against the year's Income amounted to £86,643
(as compared with £77,783 last year).

The *General Revenue Account* therefore results in a credit balance on the year of £1,441

The *General Revenue Account Surplus* amounted to £22,827 on the 31st March, 1952, made up as follows :—

Balance brought forward 1st April, 1951 . .	£21,386
Add Surplus for year to 31st March, 1952 . .	£1,441
	£22,827

Cash at Bankers and in hand amounted to £38,062 (compared with £43,308 last year) at the close of the financial year, owing to the receipt, as in past years, of a substantial proportion of the current subscriptions during the first quarter. This balance is required to finance expenditure during the remainder of the year.

The actual expenditure during the year on " Publications Account " amounted to £32,036 (compared with £28,371 last year), of which £20,887 represented the cost of the Journal, Proceedings, etc. This expenditure was relieved by credits for advertisements, sales, etc., of £9,758 (against £9,111 last year), leaving the net expenditure for the year at £22,278 (compared with £19,260).

The Repairs and Renewals Reserve credit balance has been reduced by £12,773 during the year, viz. from £28,029 to £15,256.

On Trust Funds Income Account there was received a total of £2,203 and the expenditure amounted to £1,591.

During the year sums of £30 in interest and £16 for sales of reports, etc., have been credited to the research into the Deterioration of Structures exposed to Sea-Action.

Fellowships.—The Council awarded the Culmann Travelling Fellowship for 1951–1952 to Mr L. C. E. Held, B.Sc., A.M.I.C.E., to carry out studies in Germany on the use of pre-stressed concrete, and the design and construction of modern reinforced-concrete structures.

The 1951–1952 Radley Research Studentship was awarded to Mr J. D. Geddes, B.Sc., Stud.I.C.E., to enable him to engage in post-graduate research in connexion with the bearing capacity of driven piles.

Charles Hawksley Prize.—None of the designs submitted for the 1951 Charles Hawksley Prize was considered to be of a sufficiently high standard to be worthy of the Prize. Consolation Prizes of £50 each were awarded to :—Mr H. L. Holland, A.M.I.C.E., Mr John Powlesland, Stud.I.C.E., and Mr G. D. Wilkinson, Stud.I.C.E.

Competition for the Institution Medal and Premium (London).—The Competition for the Institution Medal and Premium (London) for 1952, between undergraduates of the Colleges of London University, took place on Wednesday, the 14th May, at the Institution. The President took the Chair at the meeting, which was attended by some 90 undergraduates. The following three Papers were presented : " Automatic Gates for Water Control," by M. D. Stone, Stud.I.C.E., Queen Mary College ;

" The Design of Dams to Withstand Earthquakes," by Vincent K. Collinge, Stud.I.C.E., City and Guilds College; and " Subway Construction in New York and Toronto and Some Aspects of the American Civil Engineering Industry," by R. B. Sims, Stud.I.C.E., King's College.

There was a lively discussion on all the Papers, to which there were 39 contributions from undergraduates.

The two judges, Mr J. A. Banks and Mr H. J. B. Harding, after expressing their appreciation of the high standard of the Papers presented, are recommending to the Council that the Medal and Premium be awarded to Mr R. B. Sims of King's College. Mr Ralph Freeman, the third judge, was unable to be present owing to illness.

The 1951 award was made too late for inclusion in last year's Report. The recipient was Mr J. H. Cuckney, Stud.I.C.E., of Queen Mary College, for his Paper on " Impact on Railway Bridges."

Kelvin Medal.—The Council had pleasure in placing the Great Hall at the disposal of the Kelvin Medal Award Committee for the purpose of the presentation of the 1950 Gold Medal to Dr Theodore Von Karman of the United States. Dr W. H. Glanville presided as Chairman of the Award Committee, and the presentation was made by Lord Runciman of Doxford, President of the Institution of Naval Architects.

Conversazione.—The Conversazione was held at the Institution on the evening of the 8th June, 1951, when some 1,500 members and guests, with their ladies, were present.

Annual Dinners.—The Annual Dinner of the Institution for 1950–51 was held on the 16th October, 1951, at the Dorchester Hotel, London, when 389 members and guests were present. The Annual Dinner for this Session was held in the same place on the 1st May, 1952.

Library.—During the year 322 volumes were presented to the Library and 333 were purchased, making a total on the 31st March of 66,870 volumes (which figure includes 5,696 volumes discarded from the main stock during reorganization), and 18,631 pamphlets. 4,050 applications for the loan of books were dealt with.

The Council have decided that the time has now come to re-index the books in the Library, as the present system of indexing has been in existence since 1895. After considering various methods of indexing that might be adopted, it was decided to use the Universal Decimal Classification. The Council also decided that the method of issuing books from the Loan Library should be modernized and the system used by Public Libraries has been suitably modified and adopted.

The consequent reorganization of the Library, which involves the re-indexing of 30,000 books, is a considerable task, but is proceeding satisfactorily. The supervision of the Library was formerly the responsibility of the Publications and Library Committee, but the Council has now set up a separate Library Committee to assume this responsibility.

Good use continues to be made of the Film Library and a number of

new films have been added to the Library during the year. Members have also availed themselves of the service which provides for the loan of lantern slides.

Nominations and Appointments.—The following nominations and appointments have been made by the Council during the year :—

Dr W. H. Glanville, C.B.E. Mr W. K. Wallace, C.B.E.	British National Committee, International Society of Soil Mechanics and Foundation Engineering.
Mr W. K. Wallace, C.B.E. Dr Guthlac Wilson, S.M.	National Consultative Council, Ministry of Works.
Mr R. M. Wynne-Edwards, D.S.O., O.B.E., M.C., M.A.	Civil Engineering Advisory Committee, Ministry of Labour.
Mr A. S. Quartermaine, C.B.E., M.C., B.Sc.(Eng.).	Science Advisory Committee, British Council.
Mr W. K. Wallace, C.B.E.	General Board of the National Physical Laboratory.
Mr E. Graham Clark, C.B.E., M.C., B.Sc.	British Committee for Co-operation with UNESCO in the Natural Sciences.
Sir David Anderson, LL.D., B.Sc. Mr J. N. Peirce (Deputy)	Tribunal of Appeal, London Building Acts, 1930–1939.
Mr L. Scott White, O.B.E.	District Surveyors' Examination Board, London County Council.
Colonel W. S. Cameron	Court of the University of Sheffield.
Mr A. C. Dean, M.C., M.Sc. Mr J. D. T. Firth, B.Eng.	100th Annual Meeting Celebrations, Union of Lancashire & Cheshire Institutes.
Mr W. H. Morgan, C.B.E., D.S.O.	Frank Denning Memorial Fund Committee, Croydon.
Mr J. R. Beard, C.B.E., M.Sc.	Representative of the Founder Institutions, General Council, British Standards Institution.
Mr V. A. M. Robertson, C.B.E., M.C. Sir Arthur Whitaker, K.C.B., M.Eng.	Engineering Divisional Council, British Standards Institution.
Mr L. Scott White, O.B.E. Mr W. K. Wallace, C.B.E.	Building Divisional Council, British Standards Institution. Council for Codes of Practice for Buildings.
Mr W. K. Wallace, C.B.E.	Civil Engineering Codes of Practice Joint Committee.
Sir Jonathan Davidson, C.M.G., M.Sc.	President's Advisory Committee, Reservoirs (Safety Precautions) Act, 1930.

Mr Arthur Floyd, C.B.E., B.Sc. Dr Guthlac Wilson, S.M. Mr R. M. Wynne-Edwards, D.S.O., O.B.E., M.C., M.A.	Board of the Professional Engineers' Appointments Bureau.
Mr A. S. Quartermaine, C.B.E., M.C., B.Sc.(Eng.) Mr W. K. Wallace, C.B.E.	Engineering Joint Council.
Sir Stanley Angwin, K.B.E., D.S.O., M.C., T.D., B.Sc. (Eng.) Sir Hubert Walker, C.B.E. Sir Arthur Whitaker, K.C.B., M.Eng.	Joint Overseas Activities Committee, Institutions of Civil, Mechanical, and Electrical Engineers.

Dr W. H. Glanville represented the Institution, in June 1951, at the celebration of the Fifth Centenary of the foundation of the University of Glasgow.

International Engineering Congresses.—The British National Committee of the Permanent International Association of Navigation Congresses has taken steps to ensure that Britain plays its full part in presenting Papers at the next Congress to be held in Rome in September 1953. Arrangements have also been made to bring the activities of the Association to the notice of the Dominions and Colonies and a special effort is being made to increase the membership of the British Section.

The British Section of the International Society of Soil Mechanics and Foundation Engineering has held three informal meetings at the Institution and these have proved very successful.

The Third International Conference of the Society is to be held in Switzerland in 1953 and the British National Committee is responsible for the submission of Papers by British authors. A number of British authors have submitted summaries for the consideration of the Committee and it is anticipated that approximately 30 Papers from this Country will be submitted for discussion at the Congress.

Géotechnique is now issued free to all members of the British Section and arrangements have been made for the notices of the Society to be published in the magazine.

The First Annual General Meeting of the British Section of the International Commission on Irrigation and Drainage was held at the Institution and a British National Committee was appointed and the statutes of the British Section were adopted. The Commission is to publish annual Bulletins, and several items have been submitted by British members for inclusion in the Bulletin.

The 4th International Congress of the International Association of Bridge and Structural Engineering is to be held in Cambridge and London in

August/September 1952. The Institution is servicing the General Purpose and Finance Committee and is assisting the Organizing Committee in the general arrangements of the Congress.

Relations with Sister Institutions.—Relations with the Institution of Mechanical Engineers and the Institution of Electrical Engineers have continued to be close and cordial and the three Presidents with the Secretaries have met at frequent intervals to consider matters of mutual interest.

A Joint Engineering Conference extending from the 4th to the 15th June was organized in London by the three bodies and was attended by about 1,500 delegates and their ladies. The technical sessions were so arranged that all branches of engineering were adequately dealt with, and in the Proceedings of the Conference the Papers with discussions were printed under the following ten parts:—Railways; Sea Transport; Power; Aviation; Education and Training; Road Transport; Telecommunications; Public Health in Municipal Engineering, Water Supply and Sewerage; Gas Industry Plant, Mining and Steelworks Plant; Electrical Measurements, Television, Cables, and Lighting. The opening Session of the Conference was held in the Great Hall of the Institution, the Lord Privy Seal, the Rt Hon. Richard Stokes, opening the Conference and outlining its aims. A large number of afternoon visits were arranged and certain social functions were held including the Conversazione of the Institution. Lord Reith of Stonehaven, Chairman of the Colonial Development Corporation, delivered the closing address of the Conference in which he suggested that it seemed likely that the community would benefit if the influence of engineers in the governance of the country were to be further strengthened.

In September the Presidents and Secretaries of the three major Institutions attended the Second Conference of Representatives from the Engineering Societies of Western Europe and the U.S.A. (Eusec.), which was held in the Hague, the Koninklijk Institut van Ingenieurs acting as hosts. Matters discussed covered a wide range and one of the important results was the decision to call a conference on Engineering Education to meet in London under the auspices of the three British Institutions, the Institution of Civil Engineers to provide the Chairman and Secretariat for the organizing committee. It is expected that the Conference will be held early in 1953.

In appreciation of the assistance and enthusiasm which the three Institutions had received from the Royal Netherlands Society of Engineers in the establishment of Eusec, the Presidents, on behalf of their Institutions, have presented a silver inkstand suitably inscribed to the Dutch Society.

The three Institutions have also co-operated fully in connexion with representations made to the Ministry of Education as a result of certain proposals made by that Ministry on the subject of Higher Technological

Education. The matter is still *sub judice*, but it is hoped that the views of the three Councils may prevail and important developments take place in the technological education in this country.

In conclusion it may be noted that many other matters have been considered jointly by the three Presidents and referred to their Councils, including among other things the important question of their joint relations with other bodies.

The Roll.—The Roll of the Institution on 31st March, 1952, stood at 18,154, the changes which had taken place in it during the year ended on that date being shown in the following Table.

	1 April, 1950, to 31 March, 1951.						1 April, 1951, to 31 March, 1952.					
	Honorary Members	Members	Associate Members	Associates	Students	Totals	Honorary Members	Members	Associate Members	Associates	Students	Totals
Numbers at commencement	18	2380	8947	35	6021	17,401	16	2373	9416	36	5997	17,838
Transfers—												
Associate Members to Members	..	+87	−87	..	..		..	+82	−82	..	..	
Elections	..	2	716	1	..	+1821	2	7	703	..	..	+1688
Admissions	..	..	..	..	1080		..	..	..	..	947	
Restored to Roll	..	..	14	..	8		..	3	18	..	8	
Deceased	2	66	68	..	5		1	66	89	2	8	
Resigned	..	28	79	..	87		..	17	60	..	79	
Erased	..	2	26	..	51		..	3	25	..	50	
Elected as Associate Members	..	..	..	..	279		..		..	..	249	
Removed over-age	..	..	..	..	678	−1384	..	..	..	..	712	−1372
Failed to complete :—												
Transfer	..	..	..	..	..		..	..	..	..	..	
Election	..	..	1	..	..		..	..	..	..	..	
Admission	..	..	..	..	12		..	..	..	..	11	
						+437						+316
Numbers at termination	16	2373	9416	36	5997	17,838	17	2379	9881	34	5843	18,154

The full list of deaths and resignations is given in the Appendix III, and the Council record with especial regret the deaths of Sir Thomas Peirson Frank, T.D., Sir Roger Gaskell Hetherington, C.B., O.B.E., M.A. (Past-Presidents), and Sir Reginald Edward Stradling, C.B., M.C., D.Sc.,

Ph.D., F.R.S. (former Vice-President). The Council also record with regret the deaths of Field Marshal the Rt Hon. Lord Birdwood of Anzac and Totnes, G.B.C., G.C.S.I., G.C.M.G., G.C.V.O., C.I.E., D.S.O., M.A., LL.D., D.C.L. (Hon. Member), Guy Howard Humphreys, M.A. (Member of Council), David Barrington Brow, O.B.E., M.C., Professor Gilbert Cook, D.Sc., F.R.S., Henry Albert Cutler, Francis William MacLean, and Stanley Graham Taylor, C.B.E., B.Sc. (former Members of Council).

Acquisitions.—The Council have received, on behalf of the Institution, a portrait of Dr W. H. Glanville (President 1950–1951), painted by Edward Halliday.

A miniature of Joseph Woods (a Graduate of the Institution in 1840) and a daguerrotype showing a railway trolley which he invented have been given by Mr A. W. Hanckel.

Lord Brassey has placed on loan to the Institution, during his lifetime, a Presentation Shield given to the late Thomas Brassey (elected an Associate in 1852) on the completion of the construction of the Great Northern Railway.

The Council have also acquired a photograph, taken in 1856, of Dr Sutherland and Robert Rawlinson (subsequently President I.C.E.), members of the Sanitary Commission to the Crimea.

APPENDIX I

ORDINARY MEETINGS

Presidential Address of Mr Allan S. Quartermaine, C.B.E., M.C., B.Sc.(Eng.).

"A Laboratory Investigation of Some Bridge-Deck Systems," by F. G. Thomas, Ph.D., B.Sc., M.I.C.E., and Andrew Short, M.Sc.

"Civil Engineering Aspects of Hydro-Electric Development in Scotland," by A. A. Fulton, B.Sc., M.I.C.E.

"Festival of Britain, 1951 : The South Bank Exhibition Buildings," by Sir Hugh Casson, M.A., F.R.I.B.A., Ralph Freeman, C.B.E., M.A., M.I.C.E., and R. T. James, O.B.E., M.I.C.E.

"The Most Recent Dams by the 'Società Adriatica di Elettricità (S.A.D.E.)' in the Eastern Alps," by Dott. Ing. Carlo Semenza.

"Sewerage and Sewage Disposal in Sub-Tropical Countries, with Special Reference to South Africa and Mauritius," by E. J. Hamlin, D.Sc., M.I.C.E.

The James Forrest Lecture on the subject of The Progress of the Science of Soil Mechanics in the Past Decade, by H. J. B. Harding, B.Sc.(Eng.), M.I.C.E.

SUPPLEMENTARY MEETING

Discussion on "Relative Economics of Pre-stressed Concrete compared with other Forms of Construction—Aluminium ; Reinforced Concrete ; Steel ; and Timber."

"A General Review," by John Ratter, C.B.E., B.Sc., M.I.C.E.

"Aluminium Construction," by D. V. Pike, A.M.I.C.E.

"Reinforced Concrete Construction," by F. S. Snow, M.I.C.E.

"Steel Construction," by H. Shirley Smith, O.B.E., B.Sc.(Eng.), M.I.C.E.

"Timber Construction," by P. O. Reece, A.M.I.C.E.

"Pre-stressed Concrete Construction," by John Cuerel, B.Sc., M.I.C.E.

AIRPORT ENGINEERING DIVISION MEETINGS

" Gravel Compaction and Testing, and Concrete Mix Design at London Airport," by Harold Smith, A.M.I.C.E.

" The Influence of Multiple-Wheel Undercarriages on the Design and Evaluation of Airfield Pavements," by G. S. Cooper, B.Sc., A.M.I.C.E.

" Dowel-Bar Joints for Airfield Pavements," by J. A. Loe, B.Sc.(Eng.), A.M.I.C.E.

MARITIME AND WATERWAYS ENGINEERING DIVISION MEETINGS

" The Design and Construction of the New Deep-Water Quays at Leith," by M. C. White, B.Sc., A.M.I.C.E.

" Oil Loading and Cargo Handling Facilities at Mina Al-Ahmadi, Persian Gulf," by C. W. N. McGowan, M.A., M.I.C.E., R. C. Harvey, B.Sc.(Eng.), M.I.C.E., and J. W. Lowdon, B.Sc.(Eng.), M.I.C.E.

" Model-Tests on the Bellmouth Spillway and Outfall of the Fassideri Project," by E. S. Crump, C.I.E.

PUBLIC HEALTH ENGINEERING DIVISION MEETINGS

" Relation between Daily Rainfall and Flow of the River Shin," by R. H. MacDonald, M.A., A.M.I.C.E.

" Some Problems in the Disposal of Industrial Effluents and Domestic Wastes," by J. T. Calvert, M.A., M.I.C.E., and P. M. Amcotts, A.M.I.C.E.

Lecture on " The Impact of Radio-activity on Public Health Engineering Services," by A. Key, D.Sc., Ph.D., and A. W. Kenny, M.A., B.Sc.

RAILWAY ENGINEERING DIVISION MEETINGS

Discussion on " Economy in Railway Civil Engineering."

Introductory Notes :

(1) " Economy through Labour Productivity and Incentive Schemes," by G. C. Stevens.

(2) " Economy through Organization," by J. Taylor Thompson, M.C., M.I.C.E.

(3) " Economy by Supervision," by A. K. Terris, B.Sc., A.M.I.C.E.

(4) " Economy through Design," by P. S. A. Berridge, M.B.E., M.I.C.E.

Discussion on " Continental Railway Civil Engineering Practice."

Introductory Notes :

(1) " Observations on a Visit to the Netherlands Railways in 1950," by J. G. F. Inglis, M.A., A.M.I.C.E.

(2) " Observations on a Visit to the French Railways in 1949," by R. G. Thurtle, M.B.E., B.Sc.(Eng.), A.M.I.C.E.

" Recent Developments in Railway Curve Design," by J. C. Loach, M.Sc., A.M.I.C.E., and M. G. Maycock, B.Sc.(Eng.), A.M.I.C.E.

" Factors Involved in the Renewal of Underline and Overline Bridges, and their Influence on Design," by A. N. Butland, O.B.E., B.Sc., B.A., A.M.I.C.E.

ROAD ENGINEERING DIVISION MEETINGS

" The Development of Hot-Rolled Gravel Asphalt for Trunk and other Roads in East Anglia," by D. J. Swift, B.Eng., A.M.I.C.E.

" Some Theoretical Aspects of Road Traffic Research," by J. G. Wardrop, B.A.

" Recent Developments in Highway Bridge Design in Hampshire," by E. W. H. Gifford, B.Sc.(Eng.), A.M.I.C.E.

" Mechanical Surfacing of Roads," by S. M. Lovell, O.B.E., T.D., A.M.I.C.E., T. U. Wilson, C.B.E., T.D., M.I.C.E., and E. W. W. Richards, A.M.I.C.E.

STRUCTURAL AND BUILDING ENGINEERING DIVISION MEETINGS

" The Rapid Calculation of the Plastic Collapse Load for a Framed Structure," by B. G. Neal, M.A., Ph.D., and P. S. Symonds, Ph.D.

" Some Recent Experiments in Composite Pre-cast and In-Situ Concrete Construction, with Particular Reference to Pre-stressing," by F. J. Samuely, B.Sc.(Eng.), A.M.I.C.E.

" Buoyant Foundations in Soft Clay for Oil Refinery Structures at Grangemouth," by C. W. Pike, A.M.I.C.E., and B. F. Saurin, B.Sc.(Eng.), A.M.I.C.E.

" The Historical Development of Structural Theory," by S. B. Hamilton, Ph.D., M.Sc., B.Sc.(Eng.), M.I.C.E.

WORKS CONSTRUCTION DIVISION MEETINGS

" The Construction of Kafr el Zayat Railway Bridge," by K. E. Hyatt, B.Sc.(Eng.), A.M.I.C.E., and G. W. Morley, M.A., A.M.I.C.E.

" The Construction of Loch Sloy Dam," by James Stevenson, B.Sc., A.M.I.C.E.

" The Construction of the Caisson forming Foundations to the Circulating Water Pump-House for the Uskmouth Generating Station," by W. Storey Wilson, M.C., B.Sc., M.I.C.E., and F. W. Sully, M.I.C.E.

APPENDIX II*

GLASGOW AND WEST OF SCOTLAND ASSOCIATION

The Chairman of the Association for Session 1951–52 has been Mr James H. Murray (M.), Engineer to Renfrew County Council. Mr Murray, who succeeded Mr William Linn (M.) as Chairman, delivered his Inaugural Address on the 12th October, 1951. In his Address, Mr Murray gave a comprehensive review of the duties and responsibilities of the Engineer to a Local Authority, and discussed the wide variety of branches of engineering with which he must be familiar.

In addition to the Chairman's Address, eight Ordinary Meetings and the Annual General Meeting were held. One of these Meetings was a Joint Meeting with the Scottish Branch of the Institution of Structural Engineers, and another was a meeting of the Association in Inverness at which the Inverness Technical Society were guests. The average attendance at the meetings has been 51, a much lower figure than in the past few years.

The Student's Section has been very active and has held six meetings plus the Annual General Meeting. Three Student Members of the Association presented full length Papers, namely, " Fish Problems on Hydro-Electric Schemes," by M. F. Kennard; " Soil Stabilization," by D. Watson; and " The History and Development of the Bridges of Glasgow," by J. M. Sutherland. This last Paper was also read to the Students' Section of the Northern Counties Association, and a Student from that Association, Mr B. J. Lewis, read a Paper on " Public Health Engineering " to the Glasgow Association. This is the first exchange lecture between the two Associations and it is hoped that these exchanges will continue.

A most interesting and enjoyable evening was had at a Joint Meeting of Corporate Members and Students. This was a Brains Trust evening, the Trust being made up of Messrs R. Bruce (M.), N. E. M. Brydon (M.), Lt.-Col. R. W. Walker (M.), and Mr H. B. Sutherland (A.M.).

The Annual Dinner, held on the 29th November, 1951, in the Central Hotel, Glasgow, was a most successful function. The President, Mr A. S. Quartermaine, attended, together with the Secretary of the Institution. The attendance was 230 members and Guests.

The Students held their Annual Joint Dance with the Institutions of Mechanical and Electrical Engineers on the 1st February, 1952, and as usual it was a most enjoyable function.

In addition to a Miller Prize, Mr William Hunter, a Student of the Association, was awarded the James Prescott Joule Medal for his Paper on " A Review of Current Practices in the Purification of Domestic Water Supplies," presented to the Association last Session.

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* In this Appendix the following abbreviations are used :—Member (M.) : Associate Member (A.M.) : Student (S.).

The Association held its first Summer Meeting on the 9th and 10th May, 1952, at Dunoon. During the Meeting, a visit was paid to the Cowal Scheme of the North of Scotland Hydro-Electric Board.

During the Summer of 1951, visits were made to the D.S.I.R. Laboratories at East Kilbride, and the Glen Shira Scheme of the North of Scotland Hydro-Electric Board.

The Association, in collaboration with the University of Glasgow and the Royal Technical College, Glasgow, prepared an exhibit on the Training and Practice of the Civil Engineer in the Building and Civil Engineering Exhibition held in the Kelvin Hall, Glasgow, from the 26th March to the 12th April, 1952. A Special Meeting of the Association was held in the Kelvin Hall during the Exhibition, when Mr A. A. Fulton, B.Sc., M.I.C.E., read a Paper entitled " Civil Engineering Aspects of Hydro-Electric Development in Scotland."

Mr James A. Banks (M.) continues to represent the Association on the Council of the Institution. This is his third year of office.

NORTH-WESTERN ASSOCIATION

The Chairman for the Session has been Mr M. T. B. Whitson (M.), who is Engineer and Manager, Ashton-under-Lyne, Stalybridge and Dukinfield (District) Waterworks. Mr Whitson succeeded Mr J. D. Bird (M.) as Chairman.

In his Chairman's Address delivered at Manchester on the 11th October, 1952, Mr Whitson advised young engineers to take heed that, when they rose in their profession and became administrators, they did not lose touch with practical civil engineering. He advised them to choose some aspect of engineering which particularly attracted them and to become as expert as possible in that branch. Mr Whitson went on to give details of one or two problems which had occupied his attention during the past few years and described how these had been overcome.

Of the Association's meetings four were held in Manchester in addition to the Chairman's Address and the Dugald Clerk Lecture ; a joint meeting with the Institution of Structural Engineers was also held. At Liverpool two meetings were held and one joint meeting with the Liverpool Engineering Society. A joint meeting with the Lancashire County Engineering Society was held at Preston.

A joint visit with the Institution of Structural Engineers was paid last summer to the new " Shell " Refinery at Stanlow. The party included about 160 members of the Association.

The Annual Dinner was held at the Midland Hotel, Manchester, on the 13th March, 1952, and was attended by the President and the Secretary of the Institution. Other guests were Dr E. J. F. James, Brig. F. C. Nottingham, and the Presidents and Chairmen of the Engineering Associations of the North-West.

Mr A. C. Dean (M.) has represented the Association on the Council for the last three years.

MIDLANDS ASSOCIATION

On the 11th October, 1951, Mr M. R. Vincent Daviss (M.), Deputy Chief Engineer to the Birmingham, Tame and Rea District Drainage Board, took over the Chairmanship of the Association from Mr R. G. Braithwaite (M.) and delivered his Address as Chairman at a meeting held in the James Watt Memorial Institute.

As the main theme of his Address he traced the development of drainage and sanitation in England up to the year 1875, as indicated by the General Acts given in the Statute Book, and gave a picture of the conditions which existed in the past.

The Address was read a second time by Mr Daviss at the meeting of the Association in Loughborough later in the month.

The number of Meetings held in Session 1951–52 included eight in Birmingham, four in Loughborough, and one in Nottingham. In addition, a meeting was held in Birmingham jointly with the Institutions of Mechanical and Electrical Engineers.

The subjects dealt with were of a varied character and included Water Supply ; Bearing Capacity of Piles ; Sewage Purification ; Highway Design ; and Aircraft Design. There were four Students' Meetings at two of which Papers were read by Students. In addition there was a joint meeting with the Students of the Institutions of Mechanical and Electrical Engineers.

The visits which took place last Summer, after the Annual General Meeting o the Association had been held, were to the Austin Motor Company's factory, and t Stratford-on-Avon, at both of which ladies were present. The meeting at Stratford on-Avon, which was non-technical in character—a departure from the normal practic —was much appreciated by those who attended, visits in the past having inevitably included some Engineering Works.

Mr F. C. Vokes (M.), together with Mr H. J. B. Manzoni (M.), and Mr R. R. W Grigson (A.M.), has continued to serve on the Council. The first is a nominee o the Local Association, the second an ordinary Member of Council, and the third one of the Associate Members of Council.

In the past, the Association has published from time to time its Transactions but it has been decided to discontinue this owing to the very high cost.

The annual Dinner of the Association was held at Birmingham on the 21st Novem ber, 1951, and was attended by the President and Secretary of the Institution, the principal guest being the Lord Mayor of Birmingham.

The Council has announced that a Miller Prize has been awarded to Peter Barnes (S.) for his Paper " The Mechanism of Railway Track," read before the Association during the Session 1950–51.

Professor S. C. Redshaw (M.), who has recently taken up his duties as Professor of Civil Engineering at Birmingham University, has been elected the Students' Vice-Chairman.

NORTHERN COUNTIES ASSOCIATION

The Tees-side Branch Member, Mr J. R. A. Kenyon (M.), was the Chairman of the Association. Mr Kenyon is the Borough Engineer of Middlesbrough and gave his Address on the 10th October in Middlesbrough, and on the 19th October in Newcastle, on " The Work of the Municipal Engineer." As Middlesbrough has been particularly active in providing new housing Mr Kenyon was able to illustrate his address with many examples of up-to-date housing lay-outs.

A Joint meeting was held with the Institution of Municipal Engineers in Newcastle, and one in Middlesbrough with the Institution of Structural Engineers. The latter is now becoming an annual custom and provides a useful link in this district which is a centre of structural engineering.

Meetings in Newcastle were held as usual in the Mining Institute and in Middlesbrough in the premises of the Cleveland Scientific and Technical Institution.

The meetings covered a variety of subjects such as land drainage, generating stations, reinforced concrete, piling, new towns, structural work, tunnelling, public health, docks, hydraulic models, and bridges.

Two meetings were held in Carlisle for the many members in the west of the Association's area, one being an informal discussion in which the younger members were encouraged to take a leading part.

Of the summer visits, that paid by Tees-side members to the new works of I.C.I. Ltd at Wilton, Middlesbrough, proved very popular, and one to the new gas works at Howdon was much appreciated by Newcastle members. The latter was the subject of a Paper on the works during the succeeding session which was chosen for the joint meeting with the Institution of Structural Engineers held at Tees-side.

The majority of the papers of the Student's Section this year have been given by Students of the Association. An innovation has been an exchange with the Glasgow and West of Scotland Association, who deputed one of their Student Members to read a Paper in Newcastle, whilst a Northern Counties' Student presented a Paper in Glasgow.

Two lectures to schoolboys have been given in collaboration with the Newcastle Education Authority arranged by a joint committee comprising representatives of the Association and the Local Associations of the Electrical and the Municipal Engineers. The Annual Dinner was held at the Royal Station Hotel on the 15th November, 1951, and there was a good attendance of members and their ladies. The President was unable to attend and his place was taken by Mr H. F. Cronin, the Senior Vice-President, who was accompanied by the Secretary of the Institution.

The award of a Miller Prize to J. D. Geddes (S.) and T. W. Weddell (S.) jointly for their Paper on " Experiments on a Model of the Port of Sunderland " has been announced.

Earlier in the session the Association suffered a loss in the death of Major W. J. Steele (M.), past-Chairman. Major Steele was City Engineer of Newcastle from 1910 to 1939 and continued to attend and contribute to meetings until the time of his death.

The Association was represented on the Council for a second year by Mr W. H. S. Tripp (M.).

YORKSHIRE ASSOCIATION

The close of the 1950–51 session marked the retirement from office of Mr J. R. Roberts (M.), who had held the position of Honorary Secretary for seven years. To show their appreciation of his valuable service members of the Association had subscribed towards a television set which was presented to Mr Roberts at the Annual General Meeting.

The new Chairman, Mr H. Foster (M.), Deputy Chief Engineer of Sheffield, formally took over office from Mr F. A. Klouman (M.) at the first meeting of the 1951–52 Session at Leeds on the 28th September. In his address Mr Foster referred to the part played by the engineer in the growth of modern civilization, and how essential it was for him to have some say in the general policy for the works he constructed. It was a great misfortune for society that engineers were too much interested in each particular job to consider whether it was fundamentally desirable, or to notice in whose hands rested the decision to do it. Much of the cure lay in the hands of engineers themselves and he called on them to take a much more active part in public and civic affairs.

In addition to meetings held at the main centres of Leeds and Sheffield, meetings were held at Hull and Scunthorpe. A feature of the meeting at Scunthorpe on the 30th November, 1951, was the visit to the works of the Appleby-Frodingham Steel Company in the afternoon. Members were much impressed by the high degree of mechanization now achieved at the works. In the evening a Paper was presented by Mr K. Paterson (A.M.), Chief Mechanical and Civil Engineer at the works, on recent development. The rolling mills, amongst other places visited during the afternoon, had to be kept in operation while complete reconstruction took place. This called for all the skill and resourcefulness of the engineer and tributes were paid to Mr Paterson and others responsible for the work.

Other Papers presented during the Session dealt with structural design, sewage disposal, road and bridge works, pre-stressed concrete and reconstruction works at Hull Docks. The Dugald Clerk Lecture "Tunnelling Plant and Equipment" was repeated at Hull on the 29th February. Two joint meetings took place with the Institution of Structural Engineers, and the Institute of Sewage Purification were invited to meetings in which they had a particular interest.

During the summer months visits were made to the large construction works at Woodhead Tunnel and Baitings Dam of Wakefield Corporation.

The Annual Dinner of the Association which was to have been held on the 21st February, 1952, was postponed to the 28th April on account of the death of His late Majesty King George VI.

A dance organized by the Students section of the Institutions of Civil, Mechanical, and Electrical Engineers was held at Leeds University on the 15th December.

The proposal to form a branch in the Hull area received the approval of the Council of the Institution and the Committee are now engaged upon proposals to ensure the effective working of this branch while still preserving the ties with the main Association.

Professor R. H. Evans (M.) has been the Association's representive on the Council for the past three years but intends to relinquish this appointment at the end of this Session.

SOUTH WESTERN ASSOCIATION

The Chairman, Mr J. B. Bennett (M.), who succeeded Mr G. E. Scott (M.) in this office, is the Engineer to the City and County of Bristol. The subject chosen by Mr Bennett for his Chairman's address, delivered in Bristol on the 11th October, 1951, and repeated in Plymouth, was "The Historical Development of the Municipal Engineer." At the Bristol meeting a presentation to the retiring Honorary Secretary, Mr B. E. Ireland (A.M.), was made. Mr Ireland was succeeded as Honorary Secretary by Mr G. C. Mander (A.M.).

The Session's programme comprised some twenty meetings, of which three were held jointly with other Institutions. Three of the meetings were held at Plymouth, two at Exeter, and the remainder in Bristol. The subjects of the Papers were diverse and included bridging, soil mechanics, testing methods, quays, concreting and concrete structures, tunnelling, railway bridges, city development, and sewage disposal.

Two all-day visits were arranged. One to Gloucester and Cheltenham and the other to Taunton, Exeter, and Dawlish Warren. On the first of these the new 8 ft. diameter sewer under construction in Gloucester was visited, and also the existing sewage disposal works at Cheltenham. The other visit included the precast and pre-stressed concrete yards of British Railways (Western Region) at Taunton and Exeter, and also the sea defence works at Dawlish Warren.

In addition two half-day visits were made, one to the new Chew Valley Reservoir, near Bristol, for the Bristol Waterworks Company, and the other to the new gas works at Stapleton Road, Bristol.

The Council has announced the award, for last Session, of Miller Prizes to M. C. Purbrick (S.) for his Paper "Blanketing and Drainage of Railway Track, with particular Reference to Work carried out at Parson Street, Bristol" and to P. H. Steel (S.) for his Paper "The Reclamation of Land from the Sea."

An innovation made during the Session was the holding of monthly informal luncheons at Bristol, which, having proved successful, it is proposed to continue.

The Annual Dinner of the Association was held at the Royal Hotel, Bristol, on the 20th March, 1952. The President and Secretary of the Institution were present and among the guests were the Lord and Lady Mayoress of Bristol, the Vice-Chancellor of the University, and the Chairmen of Kindred Associations. During the course of his speech at the dinner, the President announced the news of the election, as a Fellow of the Royal Society, of Professor A. G. Pugsley (M.), Professor of Civil Engineering the University of Bristol.

Professor Pugsley, who was present at the dinner, received many congratulations from guests and fellow members of the Association.

The dinner was followed by a dance in which exhibitions of Scottish dancing were included.

The Association has been, for the past three years, represented on the Council by Mr G. G. Marsland (M.).

NORTHERN IRELAND ASSOCIATION

The 1951–52 Session opened on the 15th October, when the new Chairman, Mr William Grigor (M.), County Surveyor of County Antrim, as successor to Mr R. H. S. Patterson (M.), delivered his Address, in which he dealt with some of the works carried out by the early Road Engineers, emphasizing principles laid down by Thomas Telford over a century ago, which remain largely applicable today, and quoting certain rules used by Telford for the purpose of instructing Road Surveyors as to the maintenance of roads. Mr Grigor went on to deal briefly with the development of roads in Northern Ireland from 1832 to the present day.

Six Ordinary Meetings of Corporate Members and Students were held and the attendances at these have been good, averaging 100, which is encouraging having regard to the fact that the overall strength of the Association is in the neighbourhood of 350.

The Paper on "A Full-Scale Experiment in Bog Blasting for Road Construction" by R. D. Duncan (M.), J. S. K. Dalzell (A.M.), and F. H. P. Williams (A.M.), originally read before the Road Engineering Division at the Institution, aroused particular interest as being an account of a new method (in Ireland) of stabilizing an embankment on peat.

Mention must also be made of Mr Green's Paper, which dealt with his experience as a P.W.D. Engineer in India, and Dr Doran's Paper on his work at the Materials Testing Station at Queen's University.

A Joint Meeting with the Institution of Electrical Engineers was held, when a Paper by Mr J. R. W. Murland (A.M.) on "The Economic Use of Small Sources of Water Power" was presented.

A Students' "Evening," run entirely by the Students under their own Vice-Chairman, was held, when three short Students' Papers: (1) "A Vacation Job in Brussels on Railway Work, mainly Tunnelling"; (2) "A Typical Day's Work

and Duties of an Assistant in a Borough Engineer's Office"; and (3) "A Typical Day's Work and Duties of an Assistant in a Consulting Engineer's Office," were read and led to an animated discussion.

At Christmas, a series of three Lectures for Schoolboys on "Air Transport" was arranged and attracted a good deal of publicity in the local press. The Annual Dinner of the Association was held at the Midland Hotel, Belfast, on 29th February, 1952, and was attended by the President and Secretary of the Institution. The Right Hon. W. V. McCleery, M.P. (Minister of Commerce), and the Vice-Chancellor of Queen's University, Belfast, were among the guests.

No visits were carried out during the summer of 1951.

The Association continues to be represented on the Council of the Institution by Mr H. E. Campbell (M.), who will complete his third year in this office in November next.

SOUTHERN ASSOCIATION

The Session opened on the 8th November, 1951, when Mr J. H. Jellett (M.), Docks Engineer, Southampton, Docks and Inland Waterways Executive, who succeeded Mr F. L. Wooldridge (M.) as Chairman, delivered his Address at Southampton. Mr Jellett dealt with the works carried out in Southampton Docks since the war, with particular reference to the new Ocean Terminal completed in 1950. Other schemes, both actual and contemplated, which had as their purpose the speeding up of the turn-round of shipping or the improvement in the standard of comfort of passengers, were also described. In conclusion, Mr Jellett indicated some of the problems attendant upon the berthing and discharging of the new American liner "United States."

During the Session, meetings were held at Southampton, Brighton, Portsmouth, Chichester, Bournemouth, and Salisbury. There were ten meetings in all, including a joint meeting with the Southampton Branch of the Royal Aeronautical Society and one with the Southern and South Western Branches of the Institution of Mechanical Engineers. The general standard of attendance at these meetings has been good, the average being approximately 100 per meeting.

A Miller Prize was awarded to Mr P. W. Agnew (S.), for his Paper on "Telescopic Gangways at the New Passenger Terminal, Southampton Docks," presented when Mr Agnew was a Student member of the Association.

The Annual Summer Meeting last year was held in May. Dr W. H. Glanville (M.) and Mrs Glanville, with the Secretary of the Institution, joined 140 Members and guests for a cruise round the Isle of Wight on board M.V. "Balmoral." The Annual Luncheon was served in the ship.

Mr P. E. Sleight (M.) has been nominated to the Council for 1952–53 to succeed Brigadier A. C. Hughes (M.), who has represented the Association for the past three years.

SOUTH WALES AND MONMOUTHSHIRE ASSOCIATION

Mr Trevelyan Price (M.), Borough Water Engineer and Manager for Swansea, was elected Chairman of the Association and took office on the 11th October, 1951. As there had been a number of Chairmen within recent years who had specialized on Water Engineering, a subject which formed the basis of their Addresses, Mr Price departed from convention in his Chairman's Address and spoke generally on the education of the young engineer and particularly the student and his activities in the Institution. He made a plea for the assistance of older members in guiding the careers and giving necessary facilities for practical experience to the young engineer.

The opening meeting was the first of seven meetings to be held in Cardiff. Three other meetings were held, one at Neath, the second at Swansea, and the third, a joint meeting with the Institution of Municipal Engineers at Llanelly, was combined with a visit to Carmarthen Bay Power Station. A visit, with an attendance of more than a hundred, was also paid to the large works of the Usk River Project, one of the schemes being carried out under the direction of the Chairman. A Miller Prize for his Paper, presented last Session, "The Design of Economical Concrete Mixes," was awarded to Mr P. M. Worthington (S.).

The Annual Dinner of the Association was held in Cardiff on the 19th March, 1952, and the guests included the President and Secretary of the Institution, the Lord Mayor

of Cardiff, the Mayor of Newport, and representatives of kindred Associations. Arrangements were made for the dinner itself to terminate comparatively early so that time was available for those attending to meet each other. This arrangement was much appreciated; the Association covers a widespread area and the opportunity offered by a gathering of this character of members from various parts of the area was welcomed.

Mr Donald Lumbard (A.M.), who had been the Honorary Secretary since 1948, gave up this office last Session on moving to Birmingham. He was presented with a gift of cutlery from the Association on the occasion of the Chairman's Address. Mr Lumbard was succeeded as Honorary Secretary by Mr T. L. Lowe (M.).

Lt.-Col. R. H. Edwards (M.) continues to be the Association's representative on the Council, a position he has held for the past three years.

EDINBURGH AND EAST OF SCOTLAND ASSOCIATION

Mr Angus A. Fulton (M.), Chief Hydraulic and Civil Engineer, North of Scotland Hydro-Electric Board, has succeeded Mr E. W. Denholm (M.) to the Chair of the Association and gave his Address in Edinburgh on the 10th October. He reviewed hydro-electric developments in the Highlands, dealing briefly with schemes in operation prior to the passing of the 1943 Act, before going on to describe in more detail the many schemes initiated by his Board.

There were five Ordinary Meetings of Corporate Members and Students, with attendances which exceeded one hundred, and three "Students' Nights," all held in Edinburgh, together with a Meeting both at Aberdeen and at Dundee, jointly with the Aberdeen Engineering Society and the Dundee Institute of Engineers. One of the "Students' Nights" provided an opportunity for a joint meeting of the Students with the Associates' Section of the Edinburgh Architectural Association, which led to a lively debate, the Chair being taken by Mr L. H. Dickersen (A.M.), the Students' Vice-Chairman. Mention must be made of a Lecture on "The Use of Scale Models in the Investigation of Hydro-Electric Problems" by Professor Jack Allen (M.), delivered at Edinburgh and at Dundee, and a Lecture by Dr J. E. Richey, F.R.S., on "The Geological Aspects of Hydro-Electric Projects."

Miller Prizes have been awarded to Mr Robert McEwan (S.) for his Paper on "Planning and Design Problems involved during Industrial Site Development" and to Mr R. P. McCulloch (S.) for his Paper on "The Construction of the Power Station Foundations at Grangemouth Oil Refinery," presented to the Association during the 1950–51 Session.

A Christmas Lecture to Schools, arranged by a local Committee consisting of representatives of the Institution, the Institution of Electrical Engineers, and the Institution of Municipal Engineers, entitled "The Work of the Municipal Engineer," was given by Mr G. S. Barry, M.I.Mun.E.

Mr George Baxter (M.) and Mr W. P. Haldane (M.) have continued to represent the East of Scotland on the Council, the former as an Ordinary Member of Council and the latter as a nominee of the Association.

The President of the Institution was unable to attend the Annual Dinner of the Association held in Edinburgh on the 16th November, and his place was taken by Mr H. F. Cronin, the Senior Vice-President.

The Association has in contemplation a number of visits to works of engineering interest for the coming summer.

APPENDIX III

Deaths and Resignations

The full list of deaths is as follows (*e.* refers to election, *t.* to transfer, and *a.* to admission) :—

Hon. Member (1).—*Field Marshal the Right Hon. Lord* Birdwood of Anzac & Totnes, *G.B.C., G.C.S.I., G.C.M.G., G.C.V.O., C.I.E., D.S.O.*, M.A., LL.D., D.C.L., (*e.* 1936).

Members (66).—Henry Charles Adams (*e.* 1899, *t.* 1914); George Jamieson Allen (*e.* 1905, *t.* 1917); John James Stewart Barnhill, *O.B.E.* (*e.* 1905, *t.* 1920); *Lt.-Col.*

Ronald Wilfred Bateman, B.Sc. (*E.* 1928, *T.* 1940); *Sir* Thomas Bell, *K.B.E.* (*E.* 1904); Joseph Bent (*E.* 1907, *T.* 1919); John Bowman (*E.* 1908, *T.* 1924); David Barrington Brow, *O.B.E.*, *M.C.* (*E.* 1919, *T.* 1937) (*former Member of Council*); Charles Brownridge (*E.* 1887, *T.* 1905); Stanley Cyril Carter, *M.C.* (*E.* 1917, *T.* 1932); Angus Macleod Chapman, B.Sc. (*E.* 1932, *T.* 1945); John Martin Clark, *M.B.E.* (*E.* 1903, *T.* 1930); Fred Clements (*E.* 1908, *T.* 1919); George Robert Graham Conway, *C.B.E.* (*E.* 1910); *Professor* Gilbert Cook, D.Sc., F.R.S. (*E.* 1911, *T.* 1929) (*former Member of Council*); Percival Martin Cooper, *C.M.G.*, *O.B.E.* (*E* 1915, *T.* 1932); Albert Player Isaac Cotterell (*E.* 1887, *T.* 1903); William Francis Henry Creber (*E.* 1910); Ferdinand Leslie Creswell, *M.C.* (*E* 1914, *T.* 1931); Henry Albert Cutler (*E.* 1886, *T.* 1905) (*former Member of Council*); Elwyn Thomas Davies, *M.C.* (*E.* 1919, *T.* 1944); David Edwards (*E.* 1906, *T.* 1923); Charles Wilfrid Ellen, *M.C.* (*E.* 1919, *T.* 1932); Francis Over Everard (*E.* 1897, *T.* 1913); *Sir* Thomas Peirson Frank, *T.D.* (*E.* 1906, *T.* 1922) (*Past-President*); Victor da Silva Freire (*E.* 1905); Charles Humphrey Gilbert (*E.* 1891, *T.* 1901); Frederick Grover (*E.* 1895, *T.* 1934); Arthur Edward Hamp, *C.M.G.*, *C.B.E.* (*E.* 1912, *T.* 1929); John Harley Harley-Mason (*E.* 1904, *T.* 1936); Tom Shirley Hawkins, *O.B.E.* (*E.* 1900, *T.* 1920); *Sir* Roger Gaskell Hetherington, *C.B.*, *O.B.E.*, M.A. (*E.* 1901, *T.* 1913) (*Past-President*); Frank Hibbert, *C.B.*, *C.B.E.*, *M.C.*, *T.D.*, D.L., M.Eng. (*E.* 1922, *T.* 1930); Frederick Stephen Horner (*E.* 1913, *T.* 1934); Aubrey Everard Hughes, *M.C.*, B.Sc. (*E.* 1919, *T.* 1927); Guy Howard Humphreys, M.A. (*E.* 1922, *T.* 1931) (*Member of Council*); Bernard Maxwell Jenkin (*E.* 1892, *T.* 1901); Edwin Harold Julian (*E.* 1938, *T.* 1947); Frederick Oscar Kirby, M.Sc. (*E.* 1907, *T.* 1934); John Ross Laing (*E.* 1901, *T.* 1923); Francis William MacLean (*E.* 1883, *T.* 1897) (*former Member of Council*); *Sir* Holberry Mensforth, *K.C.B.*, *C.B.E.*, M.Sc.Tech. (*E.* 1922); George Hemingway Mills (*E.* 1903, *T.* 1911); Christopher Gibbs Mitchell, *O.B.E.*, B.Sc. (*E.* 1919, *T.* 1931); John Rhys More (*E.* 1910); Humphrey Maurice Morgans, *O.B.E.*, B.Sc. (*E.* 1920); William Purcell O'Neill (*E.* 1884, *T.* 1900); Frederick George Augustus Pinckney (*E.* 1905, *T.* 1922); Joshua Fielden Ramsbottom (*E.* 1915); Frederick Howell Rees (*E.* 1887, *T.* 1913); George Marlin Treharne Rees, *O.B.E.*, B.A. (*E.* 1914, *T.* 1933); *Professor* Frederick George Royal-Dawson (*E.* 1893, *T.* 1905); John Arthur Saner, *C.B.* (*E.* 1890, *T.* 1896); Herbert Alfred Sieveking, M.Sc. (*E.* 1930, *T.* 1941); George Greig Sinclair, *M.B.E.* (*E.* 1907, *T.* 1934); William Jones Steele, *D.S.O.* (*E.* 1899, *T.* 1913); *Sir* Reginald Edward Stradling, *C.B.*, *M.C.*, D.Sc., Ph.D., F.R.S. (*E.* 1917, *T.* 1928) (*former Vice-President*); Stanley Graham Taylor, *C.B.E.*, B.Sc. (*E.* 1929, *T.* 1939) (*former Member of Council*); John Wilbur Tierney (*E.* 1942); Vincent Turner, *O.B.E.* (*E.* 1904, *T.* 1923); *Lt.-Col.* Reginald David Walker, *O.B.E.*, *M.C.* (*E.* 1921, *T.* 1933); William Holford Mortimer Walker (*E.* 1910); William Hugh Williams (*E.* 1890, *T.* 1898); Harold Whiteman Woodall (*E.* 1908); Arthur Wood-Hill (*E.* 1896, *T.* 1909); Leo de Zinovieff (*E.* 1930, *T.* 1947).

Associate Members (89).—Alfred Seabold Eli Ackermann, B.Sc. (*E.* 1892); William Aiston (*E.* 1944); William Alexander (*E.* 1895); William Edgar Ballard (*E.* 1908); Walter Banks (*E.* 1890); William Fitz-Gerald Barry (*E.* 1890); Duncan Forrest Bauchop, *B.E.* (*E.* 1918); Robert Clive Beecroft, M.Eng. (*E.* 1925); John Frederick Black, B.Sc. (*E.* 1903); Edward Valentine Blomfield (*E.* 1910); Fred Moss Bray (*E.* 1908); Harold Grummant Buxton, B.Sc. (*E.* 1931); John George Carew-Gibson (*E.* 1893); John Carson, B.Sc. (*E.* 1946); William Joseph Chadwick, *B.E.* (*E.* 1935); Henry Angrave Chambers, (*E.* 1915); Clifford Stilwell Chaster (*E.* 1913); Rupert Lionel Colbourne (*E.* 1905); John Lionel Cridlan (*E.* 1905); John Smyth Kenneth Dalzell, B.Sc. (*E.* 1943); Charles Walter Burges Daman (*E.* 1919); William Whitridge Davies, *O.B.E.*, B.Sc. (*E.* 1926); John Howard Dixon, B.A. (*E.* 1907); Charles Philip Dreyfus, B.Sc. (*E.* 1937); William James Edwards (*E.* 1897); Sidney John Ellis (*E.* 1911); Patrick Fletcher (*E.* 1892); William Herbert Forrester, B.A. (*E.* 1950); Walter Harold Fourniss, B.Sc. (*E.* 1934); *Col. Sir* Frank Garrett, *K.C.B.*, *C.B.E.*, (*E.* 1895); Frank Douglas Gemmell, B.Sc. (*E.* 1937); Charles Herbert Goulden, *M.C.* (*E.* 1918); John Richard Hadfield (*E.* 1915); Douglas Ian Halstead, B.Sc. (*E.* 1952); Edmund Harwood (*E.* 1920); John Raymond Stuart Hawker, B.Sc. (*E.* 1917); Jacques Herbert Hedgecock, B.Sc. (*E.* 1940); George Branson Hetherington, B.E. (*E.* 1935); George Ronald Hildred (*E.* 1943); Christopher Raymond Hollingsworth (*E.* 1917); Robin Wright Holmes, B.Sc. (*E.* 1919); William Haines Hutchinson (*E.* 1895); Donald Taylor Iredale (*E.* 1948); Philip Harris Jackson (*E.* 1920); David James (*E.* 1911); Clifford Harris Jones (*E.* 1947); Elias Christopher Jones, B.Sc. (*E.* 1894); Charles Edward Knowles (*E.* 1890); Alexander Longmuir (*E.* 1918); Walter George McFadyen (*E.*

1937); Alexander Leahy McIntyre, B.E. (*s.* 1935); Robert Ferrier McKay, M.Sc. (*s.* 1919); John Douglas Midforth (*s.* 1929); James Dalton Milner, M.B.E. (*s.* 1906); John Peters Moon (*s.* 1919); Patrick David Nicholas Murphy, B.Sc. (*s.* 1930); Percival Morton Norris (*s.* 1910); Joseph William Pell (*s.* 1922); Charles Henry Peppiatt, *O.B.E., T.D.*, M.Sc. (*s.* 1930); Albert Philip (*s.* 1929); William Gordon Ponsonby, B.E. (*s.* 1914); William Henry Price (*s.* 1917); Alexander Cecil Rankin, *D.F.C., M.C.*, B.Sc. (*s.* 1919); Reginald Campbell Rattray, *M.B.E.*, B.A. (*s.* 1915); Edward Fletcher Roberts (*s.* 1913); Leslie Franklin Row (*s.* 1928); Eric William Seeman (*s.* 1920); Arthur Tom Slocombe (*s.* 1930); Alan Carrick Smith (*s.* 1921); Clifford Norman Smith, B.Eng. (*s.* 1947); Leslie Morton Smith, B.Sc. (*s.* 1930); Thomas Archibald Smithells, B.Sc. (*s.* 1920); Philip Bertie Spencer-Stanhope, M.A. (*s.* 1895); George Stanley (*s.* 1920); Percy Charles Stewart (*s.* 1899); *The Right Hon. the Earl of* Strafford (*s.* 1887); William Sutcliffe (*s.* 1910); Lothian Gordon Tessier (*s.* 1912); Sangarapillai Thanmavarather, B.Sc. (*s.* 1949); William Edmond Clason Thomas (*s.* 1887); Edgar Charles Thrupp (*s.* 1899); Roy Thornton Toogood (*s.* 1924); John Antony Vickers, M.A. (*s.* 1951); George Frederick Vollmer, M.Sc. (*s.* 1902); Harold Walmsley (*s.* 1907); Charles Harry Webb, B.Sc. (*s.* 1919); Samuel Ratnaswami Williams, B.A., B.E. (*s.* 1929); Joseph Wilson (*s.* 1919); Leslie John Wyatt, *D.S.C.* (*s.* 1932).

Associates (2).—Ernest Batchelor, B.A. (*s.* 1927); Kenneth Dundas (*s.* 1926).

Students (8).—David Anderson (*A.* 1948); George Bryan Catlow (*A.* 1950); Richard Drayton (*A.* 1947); Derek Grey Lomax (*A.* 1949); John Malcolm McKinley B.Sc. (*A.* 1945); Geoffrey Alan Maisey, B.Sc. (*A.* 1947); Colin Bernard White (*A* 1948); Howard Godfrey Wright (*A.* 1950).

The following resignations have been received:—

Members (17).—Stanley Allen-Magill, B.Sc., (*s.* 1921, *T.* 1932); Ronald Bugler Aries (*s.* 1908, *T.* 1922); Alexander Fryear Dickinson, *M.C.*, B.Sc. (*s.* 1912, *T.* 1930); Edward Errington Fea (*s.* 1908, *T.* 1943); Hubert Maurice Gorringe, *M.C.*, B.Sc. (*s.* 1913, *T.* 1936); Fleetwood Keighley-Peach (*s.* 1925); Harry Cromwell Lamb (*s.* 1934); Henry Alexander McGillycuddy, B.E. (*s.* 1910, *T.* 1937); *Rao Bahadur* Bhaskar Laxman Modak, *M.C.E.* (*s.* 1922, *T.* 1934); Hugh Edmund Moffatt (*s.* 1915, *T.* 1934); Frederick Robert Morgan (*s.* 1931); Henry Walter Huntingford Richards (*s.* 1934); Cecil Joseph Robinson, *M.C.*, B.Eng. (*s.* 1922, *T.* 1931); Thomas Peter Miller Somers, *C.B.E.* (*s.* 1925); William Alfred Tookey (*s.* 1930); Robert William Watson (*s.* 1911, *T.* 1931); Thomas Watson, *M.C.* (*s.* 1920, *T.* 1938).

Associate Members (60).—Frederick James Ainlsey (*s.* 1912); Alexander Dill Anderson, B.E., B.A. (*s.* 1914); Sorab Dinshaw Bamjee, B.Sc. (*s.* 1919); James Bleakley (*s.* 1922); Charles Alfred Breeze, B.Sc. (*s.* 1923); Kenneth Brown (*s.* 1913); Frederick Arthur Buckley, B.A., B.A.I. (*s.* 1949); Harold Victor Budgen (*s.* 1924); George Ludvic William Butterworth (*s.* 1915); Alexander Cheyne (*s.* 1925); John Clemishaw (*s.* 1913); Thomas Arthur John Dickens, B.Sc. (*s.* 1938); Henry Chudleigh Dorman, B.E. (*s.* 1914); Percy Tucker Easton, *M.C.* (*s.* 1914); George Gray Forster (*s.* 1916); Bertram Douglas Fox, B.A. (*s.* 1908); Frederick Reginald Gibbins, B.Sc. (*s.* 1910); Wesley Hancock, M.Sc., Ph.D. (*s.* 1939); Charles Edward Holloway, B.Sc. (*s.* 1917); William Jamieson (*s.* 1901); Thomas Herbert Jones, M.Sc.Tech., B.Sc. (*s.* 1925); Robert Leslie Kaye (*s.* 1917); Alexander Milroy Kennedy, B.A. (*s.* 1941); George Whitaker King, B.E. (*s.* 1914); Nikolas Jordan Kirov, M.Sc. (*s.* 1948); Charles Douglas Knights (*s.* 1935); Harold Smith Laverack, *M.C.* (*s.* 1913); James Legg, *I.S.O.*, B.Sc. (*s.* 1918); Arthur Lister-Jackson, B.Sc. (*s.* 1920); John Ernest McDougall (*s.* 1909); Ernest Edwin Mann, M.Sc. (*s.* 1906); Edwin Hope Marfleet (*s.* 1932); Alec Lea Mitchell, B.A. (*s.* 1908); Frederick Victor Murdock, B.A.I. (*s.* 1939); Philip Alexander Oppenheim, *M.M.* (*s.* 1924); Gilbert Paterson (*s.* 1913); Walter Arnold Copland Perry, B.A. (*s.* 1925); Trevor Watts Phillips, B.Sc. (*s.* 1919); Walter Devereux Pile (*s.* 1913); Arthur Pope (*s.* 1907); William Stuart Rashleigh (*s.* 1908); Alexander Richardson, B.Sc. (*s.* 1907); William Owen Ridley (*s.* 1914); Douglas Fletcher Roberts (*s.* 1928); Ernest Robinson, B.Sc. (*s.* 1919); Harold Wood Robinson, B.A. (*s.* 1933); Harold Sanderson (*s.* 1911); Leslie Senior (*s.* 1919); Royle Herbert Shaw, B.Sc. (*s.* 1917); Donald Elliott Smith, (*s.* 1911); George Smith (*s.* 1915); John Alan Stein, *C.I.E.* (*s.* 1918); Geoffrey Alden Stevens (*s.* 1919); William Robert Thomson, B.Sc.Tech. (*s.* 1923); John William Trodd (*s.* 1911); Charles Brandon Trye (*s.* 1926); Hubert Lionel Tucker (*s.* 1944);

Fergus Campbell Tudball, B.Sc. (*E.* 1931); Reginald Ayton Winfield (*E.* 1919); Thomas Guthrie Young, B.Sc. (*E.* 1922).

Students (79).—Stanley MacDonald Anderson (*A.* 1948); Richard Harry Barden (*A.* 1949); Bernard William Barr (*A.* 1947); Paul Stephen Donald Basson, B.Sc. (*A.* 1950); William Neil Blackburn, (*A.* 1948); Benjamin Blakemore (*A.* 1948); George Cargill (*A.* 1943); James Clarkson (*A.* 1946); George Brian Colbridge (*A.* 1945); Robert Guy Connal (*A.* 1948); Douglas Low Crawford (*A.* 1947); Eric James Crowch (*A.* 1943); Ian Cunningham (*A.* 1945); Michael John Mead Cutting (*A.* 1947); John Michael Denham (*A.* 1949); William Alexander Donaldson (*A.* 1946); David Drabble (*A.* 1948); Anthony George Dutton (*A.* 1945); John Rustell Easton (*A.* 1950); Dennis Edwards (*A.* 1948); Derek Thomas Envine (*A.* 1948); John William Garnett (*A.* 1944); John Hood Gemmill (*A.* 1946); Thomas Gordon (*A.* 1946); George Malcolm Harper (*A.* 1946); Norman Patrick Hart (*A.* 1949); John Charles Hopkins (*A.* 1944); Alastair Charles Hunter (*A.* 1949); Warwick Hutchings (*A.* 1946); Raymond Curtis Jacklin (*A.* 1950); Thomas Peter Jenkinson (*A.* 1946); David Newman Johnson (*A.* 1950); Stuart Johnson (*A.* 1946); William McMillan Johnston (*A.* 1949); Thomas Aylmer Kenny (*A.* 1948); Handel Kitchener Lawson (*A.* 1944); Thomas Hendry Legget (*A.* 1945); Geoffrey Keith Lewis (*A.* 1947); David Russell Lillie (*A.* 1946); Alexander Carter Livingston (*A.* 1950); John Long (*A.* 1950); Edward Geoffrey Ludlow, B.A. (*A.* 1946); Brian Forrester Charles Macaulay (*A.* 1946); David Anthony McGrotty (*A.* 1950); Keith Martin, B.A. (*A.* 1949); Peter St. Cyr Michau (*A.* 1949); Barry Mitchell (*A.* 1943); Ronald Stephen Mowll (*A.* 1949); Allan Burrell Newland (*A.* 1945); Roy David Newman (*A.* 1948); Wilfred Ernest Patton (*A.* 1948); Thomas Oliver Penman (*A.* 1944); Derek Albert Pimble (*A.* 1945); Ivan John William Pothecary (*A.* 1946); Richard Prosser (*A.* 1948); Kenneth Samuel Randall (*A.* 1949); Edmund Daly Revington (*A.* 1949); Donald Allister St. John (*A.* 1950); Anthony Philip Sartain (*A.* 1949); Anthony William Seal (*A.* 1943); Liam Gerard Sharkey (*A.* 1949); George Siree (*A.* 1945); Peter Frederick Smith (*A.* 1945); Donald Herbert Stanley (*A.* 1945); Thomas Stewart (*A.* 1947); John Howard Strivens (*A.* 1946); Andrew Ik Bie Tan (*A.* 1949); David William Tapping (*A.* 1950); Lewis Myer Taylor (*A.* 1948); James Anthony Tibbetts (*A.* 1946); Albert George Tyler (*A.* 1945); Allan James Warbrick (*A.* 1944); Raymond Frank Waterhouse (*A.* 1948); Leslie Stuart Watt (*A.* 1949); Peter Wells (*A.* 1950); Alan Ewen Whitwell (*A.* 1949); Francis George Wilks (*A.* 1945); Edward John Worlidge (*A.* 1949); Alan Yates (*A.* 1945).

BALANCE SHEE

31 March 1951		£	s.	d.	£	s.
£	**INSTITUTION CAPITAL ACCOUNT**					
414,759	*As per last Account*				414,758	16
	INSTITUTION BUILDING SINKING FUND					
	As per last Account	928	5	3		
	Add : Allocation for year to date	450	0	0		
	Interest on Investments and Income Tax refunded	43	9	5		
928					1,421	14
	REPAIRS AND RENEWALS RESERVE					
28,029	*As detailed on page 500*				15,256	8
	GENERAL REVENUE ACCOUNT SURPLUS					
	Balance at 31st March, 1951	21,386	4	11		
	Add : Surplus for the year to date, *page 501* . . .	1,440	17	10		
21,386					22,827	2
465,102					454,264	2
	CREDITORS—					
	Sundry Creditors	15,211	16	7		
	War Memorial Fund	686	9	11		
13,657					15,898	6
	REVENUE IN SUSPENSE					
	Proportion of subscriptions and examination fees received relating to the period after 31 March,					
38,263	1952				42,993	13
517,022					513,156	2
	TRUST FUNDS					
	Capital Accounts	67,887	14	0		
	Unexpended Income—					
	Balance per last account . . 7,327 16 1					
	Add : Income received for the year to date 2,203 7 6					
	9,531 3 7					
	Less : Expenditure on Scholarships, Prizes, Lectures, etc. . 1,591 6 4					
74,280		7,939	17	3		
					75,827	11
	SEA ACTION COMMITTEE ACCOUNT—					
	Balance at 31st March, 1951	1,001	0	0		
	Add : Interest and other receipts for the year to date	46	6	6		
		1,047	6	6		
	Less : Expenditure for the year to date . . .	106	19	11		
1,001					940	6
592,303					£589,924	0

REPORT OF THE AUDITORS TO THE MEM

We have obtained all the information and explanations which to the best of our knowled
kept by the Institution so far as appears from our examination of those books. We have ex
of account. In our opinion and to the best of our information and according to the explan
31st March, 1952, and the general revenue account gives a true and fair view of the surplus

London, 9th May, 1952

IL ENGINEERS

31ST MARCH, 1952

31 March 1951 £		£ s. d.	£ s. d.
	FREEHOLD PROPERTY—INSTITUTION BUILDING—		
375,768	*At cost, as per last Account*	..	375,767 16 10
	INSTITUTION INVESTMENTS (including those held in respect of Repairs and Renewals		
93,878	Reserve) at or under cost	..	93,878 7 5
	Market value, £79,807—(1951, £89,297)		
	INSTITUTION BUILDING SINKING FUND		
915	Investments at cost	1,378 5 3	
	Market Value, £1,127—(1951, £853)		
13	Cash awaiting investment	43 9 5	
			1,421 14 8
3,140	**DEBTORS**		4,025 5 4
43,308	**BALANCES AT BANKERS AND CASH IN HAND**		38,062 18 1
517,022			513,156 2 4
	TRUST FUND ASSETS—		
	Capital :—		
	Investments 67,793 17 2		
	Market value, £51,764—(1951, £58,355)		
	Balance at Bankers 93 16 10		
		67,887 14 0	
	Unexpended Income—		
	Investments 437 0 11		
	Market value, £324—(1951, £373)		
	Balance at Bankers 7,502 16 4		
		7,939 17 3	
74,280			75,827 11
	SEA ACTION COMMITTEE ACCOUNT—		
	£1,000 3% Savings Bonds 1955/65 at cost . .	1,000 0 0	
	Balance at Bankers	46 11 6	
		1,046 11 6	
	Less Due to Creditor	106 4 11	
1,001			940 6 7
592,303			£589,924 0 2

E. GRAHAM CLARK, *Secretary*,

HE INSTITUTION OF CIVIL ENGINEERS.

were necessary for the purposes of our audit. In our opinions proper books of account have been
ove Balance Sheet and annexed general revenue account which are in agreement with the books
us the said Balance Sheet gives a true and fair view of the state of the Institution's affairs at the
nded on that date.

ALAN RAE SMITH
J. D. C. COUPER } AUDITORS.

RESERVES FOR REPAIRS AND RENEWALS TO STRUCTUR FURNITURE, FITTINGS AND MACHINERY

1950–51 £		£ s. d.	£
28,031	BALANCE, per last account		28,029
	Add CREDITS during the year—		
560	Interest on investments and Income Tax refunded Institution Revenue Account—		559
2,500	Amount provided for the year, *page 501*		2,500
31,091			31,089
3,062	Less NET EXPENDITURE during the year		15,832
28,029	BALANCE carried forward, per Balance Sheet, *page 498*		15,256

PUBLICATIONS EXPENDITURE

	To EXPENDITURE during the year—		
16,548	Journal, Proceedings, etc.	20,887 9 5	
2,099	"Chartered Civil Engineer"	1,971 17 7	
813	Charters, By-laws and Lists of Members	912 17 3	
680	Engineering Abstracts	815 3 7	
6,505	Salaries and Pension Premiums	6,338 17 8	
901	Miscellaneous Publications	830 18 0	
221	Reporting	316 11 4	
93	Sundry Expenses	6 5 4	
511	"Géotechnique"—Expenditure less Receipts	— — —	
28,371		32,080 0 2	
—	Less "Géotechnique"—Receipts less Expenses	43 14 8	
		32,036 5 6	
9,111	do Credits for Advertisements, Sales, Subscriptions, etc.	9,758 14 5	
19,260	As per General Revenue Account, *page 501*		22,277 1

RESEARCH EXPENDITURE

	To EXPENDITURE during the year—			
1,581	Salaries and Pension Premiums	1,853 3 5		
36	Travelling to Committees	18 6 10		
84	Printing of Sundry Reports	264 19 1		
2	Sundry Expenses	6 8 6		
1,703				
652	Less Sales of Proceedings and Reports			2,142 17
				469 15
1,051	As per General Revenue Account, *page 501*			1,673 1

GENERAL REVENUE ACCOUNT FOR THE YEAR ENDED 31ST MARCH, 1952

1950–51 £	INCOME.	£ s. d.	£ s. d.
64,515	Subscriptions received applicable to the financial year 1951–52	..	66,251 10 8
8,412	Entrance Fees	..	10,007 8 0
—	Life Composition	..	250 0 0
	Interest, Dividends, etc.—		
	On Institution Investments	1,903 12 3	
	On Deposit Account less Interest paid	73 6 1	
	Income Tax recovered for the year 1950–51	552 2 5	
2,317			2,529 0 9
8,246	Examination Fees for the April and October 1951 Examinations	..	8,613 16 6
112	Higher National Certificates—receipts less expenses	..	158 15 10
301	Library Fund Donations	..	274 5 6
83,903	TOTAL INCOME	..	88,084 17 3

Deduct EXPENDITURE.

12,986	House and Establishment Charges	14,382 18 6	
2,500	Repairs and Renewals Reserve—Amount provided for the year, *page 500*	2,500 0 0	
20,345	Salaries and Wages (including staff pensions premiums)	20,625 8 8	
3,115	Stationery, Postage, etc.	5,642 18 4	
19,260	Publications—*see page 500*	22,277 11 1	
1,051	Research—*see page 500*	1,673 1 11	
3,734	Library	3,842 4 1	
—	Library Reorganization	465 6 6	
5,802	Examination Expenses	6,628 14 11	
	Grants and Contributions—		
—	Local Associations 4,028 13 3		
—	Overseas Advisory Committees 82 0 8		
—	Other Bodies 114 14 8		
3,869		4,225 8 7	
—	Annual Dinner	348 8 3	
755	Conversazione	933 4 7	
258	Legal and other Professional Charges	261 14 6	
517	Public Relations Committee Expenses	443 12 8	
2,141	Engineering Conferences	783 5 8	
816	Travelling Expenses to Committees	910 0 7	
184	Other Expenses	250 0 7	
450	Institution Building—Sinking Fund Allocation	450 0 0	
77,783	TOTAL EXPENDITURE		86,643 19 5
Surplus 6,120	Balance, being Surplus for the Year carried to Balance Sheet		£1,440 17 10

OBITUARY

PROFESSOR SIR CHARLES EDWARD INGLIS, O.B.E., who died suddenly in Southwold, Suffolk, on the 19th April, 1952, at the age of 76, was born in Worcester on the 31st July, 1875.

Educated at Cheltenham College, he became a Scholar of King's College, Cambridge, in 1894, obtaining a first class in the Mechanical Sciences Tripos in 1898. On leaving Cambridge he was apprenticed to the late Sir John Wolfe Barry, Past-President, later becoming assistant engineer on works of public importance, including a section of the London Underground Railway. He returned to Cambridge in 1901, on his election to a Fellowship of his old College, King's : he was at first assistant in the Engineering School, but was subsequently appointed University Lecturer in Engineering.

On the outbreak of war in 1914 he was commissioned in the Corps of Royal Engineers, and from 1916 to 1919 was in charge of the department designing and supplying military bridges, and it was in that capacity that he designed the Inglis portable tubular bridge and the Inglis tubular observation tower.

In 1918 he retired with the rank of major and was awarded the Order of the British Empire (Military Division). Returning to Cambridge he became Professor of Engineering, a post he held until his retirement in 1943.

He was a prolific writer on engineering matters, contributing Papers and treatises to many scientific bodies. His published works include the Report of the Bridge Stress Committee published in 1929 by H.M. Stationery Office, and his book " A Mathematical Treatise on Vibrations in Railway Bridges " (1924), which can be regarded as the classical work on the subject.

His election as a Fellow of the Royal Society in 1930, and the award of an Honorary Doctorate of Laws by the University of Edinburgh were just recognition of his work in the field of vibrations and stresses in structures. His vast knowledge of this subject led to his appointment as an assessor to the inquiry into the loss of the Airship R101 in 1930.

In 1945 he was granted a knighthood for his public services.

Sir Charles Inglis was President of the Institution of Civil Engineers in 1941, having been Vice-President in 1938. First elected to the Institution as Associate Member in 1901, and transferred to the class of Member in 1923, he became a Member of Council in 1928.

His contributions to the Institution were many and included a Student's Paper on " The Geometrical Methods in investigating Mechanical Problems " for which he was awarded a Miller Prize in 1901, a Paper on " The Theory of Transverse Oscillations in Girders and its Relation to Live Load and Impact Allowance " [1] for which he was awarded a Telford Gold Medal in 1924, and a Paper on " Impact in Railway Bridges."[2] His latest

published work was " Applied Mechanics for Engineers." He delivered the Trevithick Memorial Lecture before the Institution in 1933, and the fiftieth James Forrest Lecture on " Mechanical Vibrations, their Cause and Prevention " [3] in 1944.

His interests were not, however, confined to the Institution of Civil Engineers alone, for not only was he Past-President of the British Waterworks Association but also a member of the councils of the Institution of Naval Architects, the Institution of Structural Engineers, and the Institution of Mechanical Engineers before which he delivered the Thomas Hawksley Lecture on " Gyroscopic Principles and Applications," in 1943.

Lady Inglis, whom he married in 1901, died on the 1st April, 1952 ; there are two surviving daughters.

JOHN ARTHUR SANER, who died on the 20th February at the age of 87, was born on the 11th August, 1864. He was educated privately and then for three years was an articled pupil of the late R. A. Marillier of the Hull Dock Company.

At the age of 21, he was appointed Assistant to the late L. B. Wells, Engineer to the River Weaver Trustees and, when the latter retired two years later in 1887, he became Resident Engineer and, in 1888, Engineer. In 1919 he was appointed General Manager in addition, and when he retired in 1934 his services as a consulting engineer were retained until the River Weaver Navigation Trust came under the control of the British Transport Commission.

During his forty-five years as Engineer, he was responsible for extensive schemes of construction and alteration involving bridges, locks, sluices, embankments, and docks. He installed electrical plant for swing-bridge operation, converted the Anderton Boat Lift from hydraulic to electrical power, and rebuilt the Hale Head Lighthouse. He also reported on schemes for improving the waterways from Birmingham and Stoke-on-Trent to the Mersey estuary, and inspected numerous reservoirs as required by the (Safety Provisions) Act of 1930.

His association with the Institution was long and active. Elected an Associate Member in 1890, he was transferred to full membership six years later. He was awarded a Telford Medal for a Paper entitled " On Waterways in Great Britain " in 1906, and subsequently wrote two other Papers and was awarded a Telford Premium. He delivered Vernon-Harcourt Lectures in 1913 and 1934, and was President of the Manchester Local Association of the Institution from 1905 to 1906.

In addition to the professional and engineering activities just outlined, he served on a variety of civil administrative boards and committees, ranging from the Upper Mersey Navigation Commission to the Boy

[1] Min. Proc. Instn Civ. Engrs, Vol. CCXVIII (1923–24, Part II), p. 225.
[2] *Ibid.*, Vol. 234 (1931–32, Part II), p. 358.
[3] J. Instn Civ. Engrs, Vol. 22, p. 312 (Oct. 1944).

Scouts Association. From 1883 to 1921 he served continuously in the Volunteers and the Territorials, being gazetted Honorary Colonel in 1905. When placed on the retired list in 1921 he retained his seat on the Territorial Association. In 1937 he was appointed Deputy Lieutenant for the County Palatine of Chester. His services were recognized by the award of the Order of the Bath in the 1939 Birthday Honours.

He was married in 1892 to Miss E. M. Jameson, and is survived by his son and two daughters.

HENRY ALBERT CUTLER, who died at the age of 91 at Groomsport, County Down, on the 6th March, was born in South Hackney on the 22nd January, 1861. He was educated privately and at King's College, London, and was articled to the late A. T. Walmisley from 1879 to 1882.

For the next four years he worked as assistant to the Municipal Engineer of Barrow-in-Furness, in the drawing office and on a high-level bridge approach, the Newbarnes Valley sewer, and Roose Road. In 1886 he returned to Mr Walmisley's service as Chief Assistant in the latter's work on bridges and harbours, but three years later obtained a post as Resident Engineer in charge of the flood works and a part of the sewerage of Leicester. In 1891 he moved again, to be Borough Engineer of Rawtenstall, where he supervised the construction of tramways, and designed and built several public buildings. In 1897 he crossed to Ireland and for six years was City and Water Engineer of Cork, where he was responsible for the underpinning and restoration of the municipal buildings, the construction of tramways, and the execution of flood prevention and water filtering and pumping schemes.

In 1903 he left Cork to be City Surveyor of Belfast, where he remained until his retirement in 1926. Projects for which he was responsible at Belfast, apart from his routine work, included a drainage scheme for two districts, purification works for the sewerage for the whole city, and the installation of tramways and their power supply.

Mr Cutler was elected an Associate Member of the Institution in 1886, and transferred to full membership in 1905. He was a Member of Council from 1924 to 1927. In 1886 he was awarded a Miller Prize for a Paper read before Students of the Institution, and about that time was co-author with Edge of a book " Curve Tables."

CORRIGENDUM

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p. 298, line 3 from bottom, *for* " stream " *read* " stress "

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